The ELESCO SUPERHEATER for Power Plants

THE SUPERHEATER COMPANY
NEW YORK

The Elesco Superheater *for* Power Plants

A catalog describing and illustrating the design, construction and application of the Elesco superheater to power plants

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BULLETIN T-1

THE SUPERHEATER COMPANY
17 East 42nd Street, New York

Peoples Gas Building
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The engineers of the marine division are available to visit any American or foreign ship equipped with Elesco (Schmidt) type superheaters. Superheater spare parts furnished for all these ships.

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The Elesco Superheater *for* Power Plants

THE growth of the Superheater Company, designing engineers and manufacturers of Elesco superheaters, closely parallels the development of the use of high degree superheated steam in the United States. When The Superheater Company was organized in 1910 as Locomotive Superheater Company, superheated steam had been applied in stationary and marine boilers with 50 to 100 degrees of superheat, or "low degree" superheat, the limit of the usual practice. Also, to a very limited extent, superheaters had been applied to locomotives on only a few railroads. At that time, however, continental European practice was much in advance of our own, largely due to the efforts of the late *Dr. William Schmidt* of Cassel, Germany.

The Superheater Company controls the American patent rights of *Dr. Schmidt* and, like him, has been a consistent advocate of the use of high degree superheat, of 100 to 200 and 300 degrees wherever possible. *Dr. Schmidt's* work covered a period of nearly 40 years and he was the first to put superheated steam on a practical and successful economic basis.

The major constituents of all parts of the steam power plant have undergone considerable change and improvement during the last fifteen years. As the largest superheater manufacturer in the United States during this period, the company has studied and followed this progress and has developed the Elesco superheater for stationary power plants accordingly. The Superheater Company is therefore in a position to offer superheater designs to meet all conditions and in accordance with latest practice.

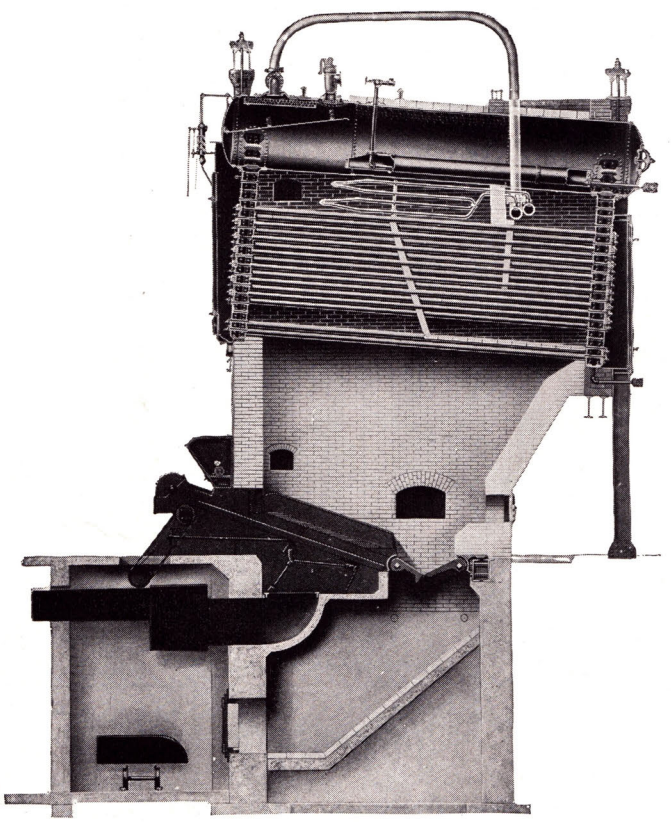

FIG. 1 Convection Type Elesco Superheater in a Heine Horizontal Longitudinal Drum Boiler (Vertical Baffles).

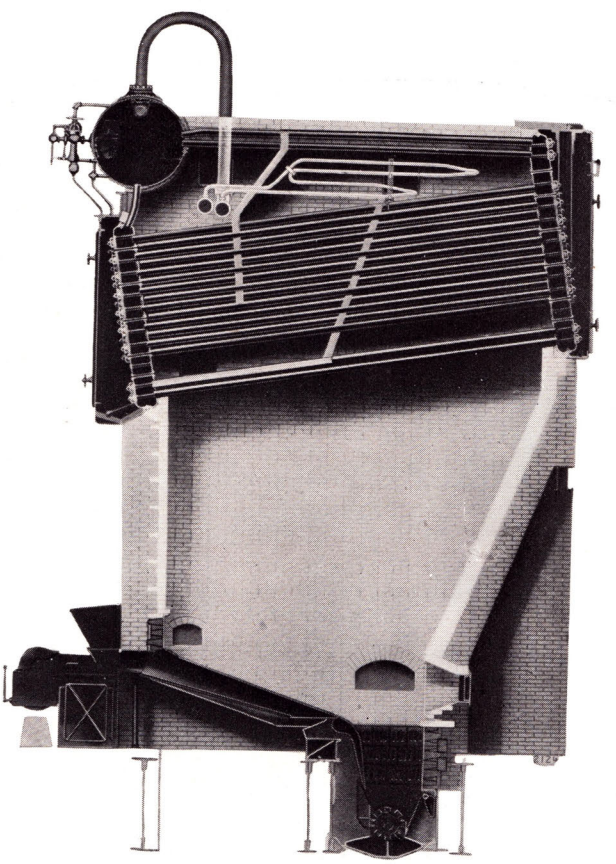

FIG. 2 Convection Type Elesco Superheater in a Heine Horizontal Cross Drum Boiler.

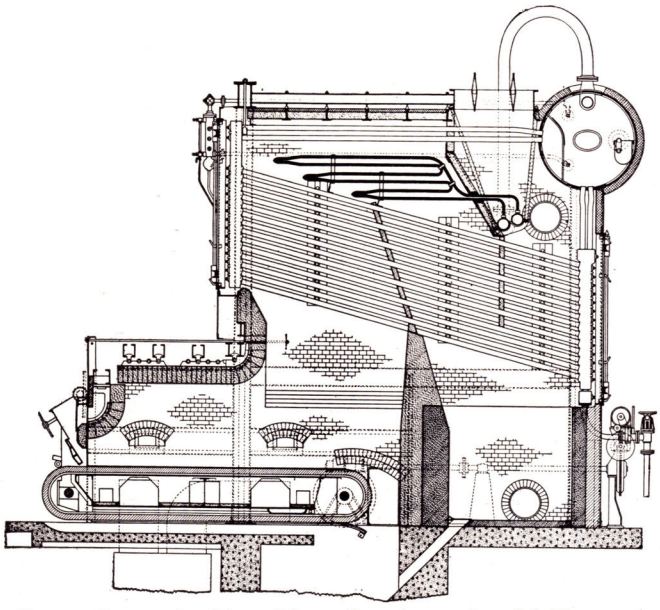

FIG. 3 Convection Type Elesco Superheater in a McAleenan Sectional Header Horizontal Cross Drum Boiler.

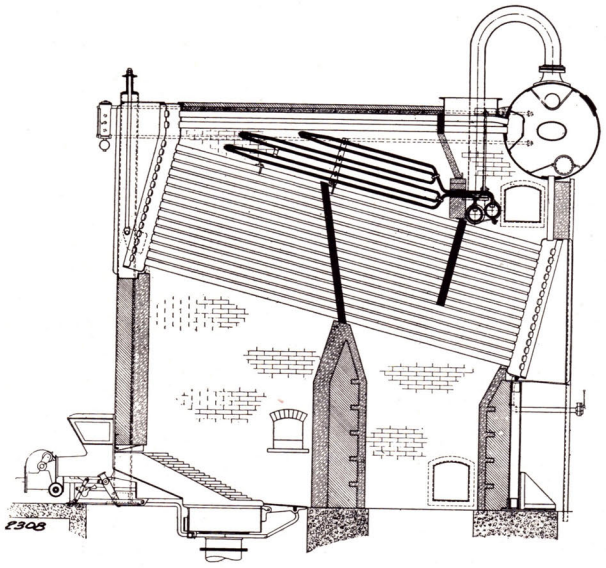

FIG. 4 Convection Type Elesco Superheater in an O'Brien Horizontal Cross Drum Boiler.

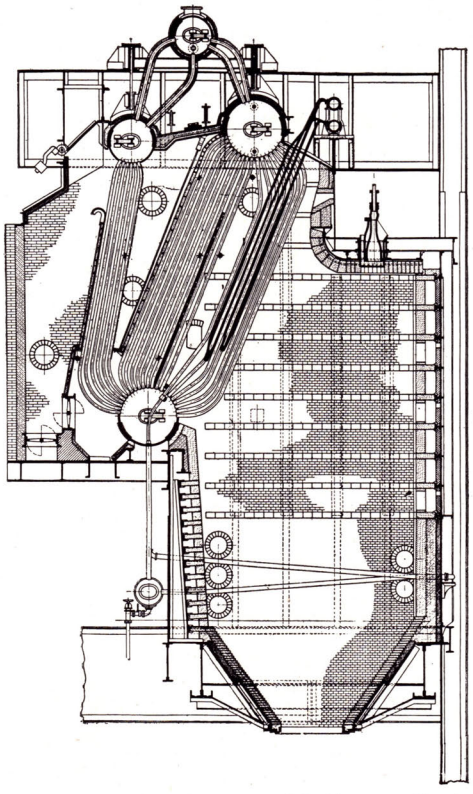

FIG. 5 Elesco Superheater in a McAleenan Semi-vertical Boiler Arranged for Pulverized Fuel Firing.

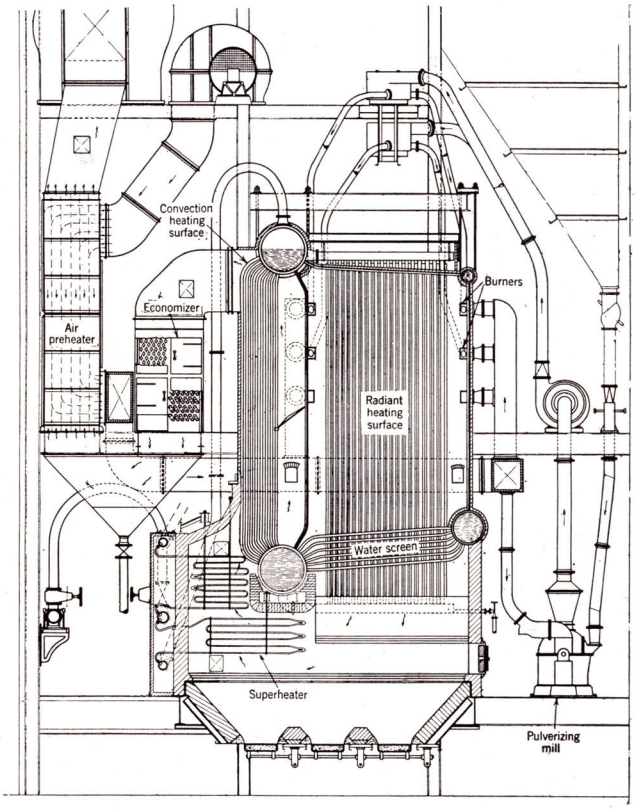

FIG. 6 Elesco Superheater in a Combustion Steam Generator.

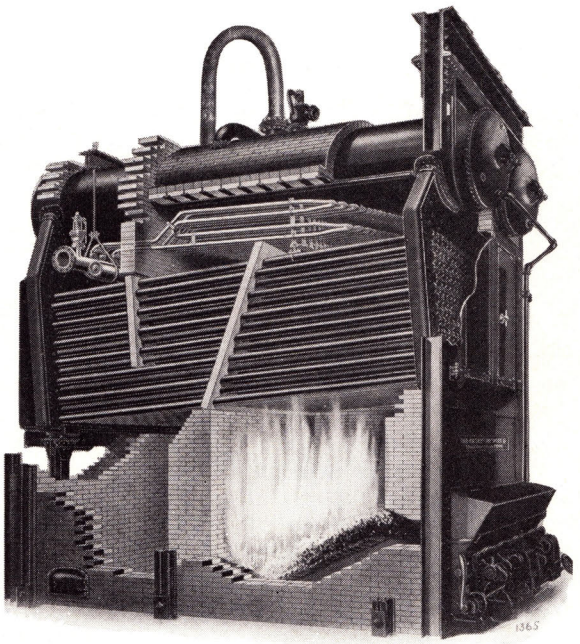

FIG. 7 Convection Type Elesco Superheater in a Hedges Walsh Weidner (Casey-Hedges Type) Horizontal Longitudinal Drum Boiler.

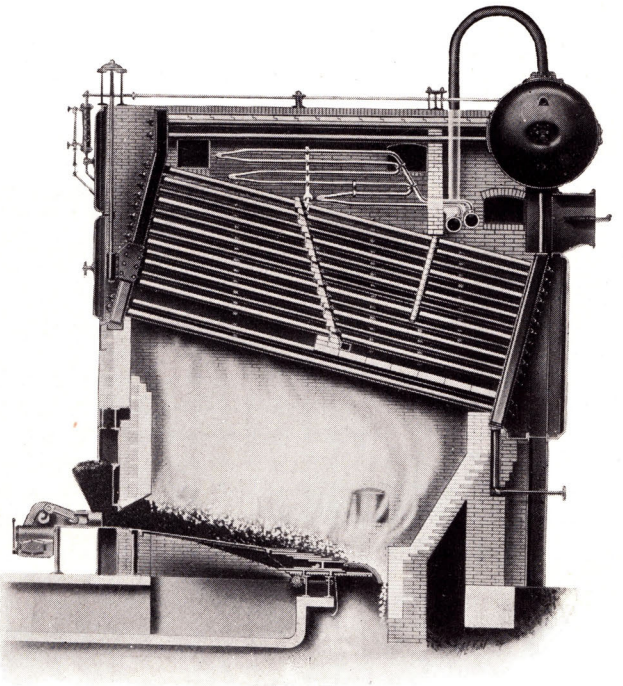

FIG. 8 Convection Type Elesco Superheater in a Hedges Walsh Weidner (Casey-Hedges Type) Horizontal Cross Drum Boiler.

PER dollar invested, the application of high degree superheated steam produces a greater and more positive increase in the efficiency of steam power plants than any other single factor in steam engineering today. New plants, practically without exception, are fitted with superheaters. In the older plants, even in those equipped with cast iron fittings and reciprocating engines, superheaters can be used always, and the less efficient the plant, the greater the resulting economy.

In order to cope with the exhaustive studies of boiler design, methods of combustion and heat balance which is demanded by the higher temperatures and higher pressures, the generation of superheated steam and its proper application demand engineering and experience second to none in the power field. There is an ever-increasing number of boiler manufacturers, consulting engineers and steam power plant engineers in the industrial and central station fields in this country and abroad who present their problems to The Superheater Company and its affiliations for advice and designs. To what extent such recommendations have proved successful is exemplified in the fact that installations aggregating more than one hundred million horsepower have been equipped with Elesco superheaters. They include superheaters in all styles of boilers and for all purposes.

The Elesco superheater has been developed as a result of practical experience gained by our engineers here and abroad during years of service in the work of increasing fuel economy. The design offers the proper means for correctly applying the art of superheating steam in the stationary power plant field. This field includes in its scope all plants where steam is generated for power purposes, irrespective of the kind of fuel or the method of firing.

After a brief study of the basic principles and the constructional details given herein, it will be appreciated that the Elesco superheater follows sound engineering, theoretically and practically. Furthermore, it will be apparent that its success is due not only to the adoption of correct principles in design, but also to its correct adaptation to the individual conditions of a particular plant.

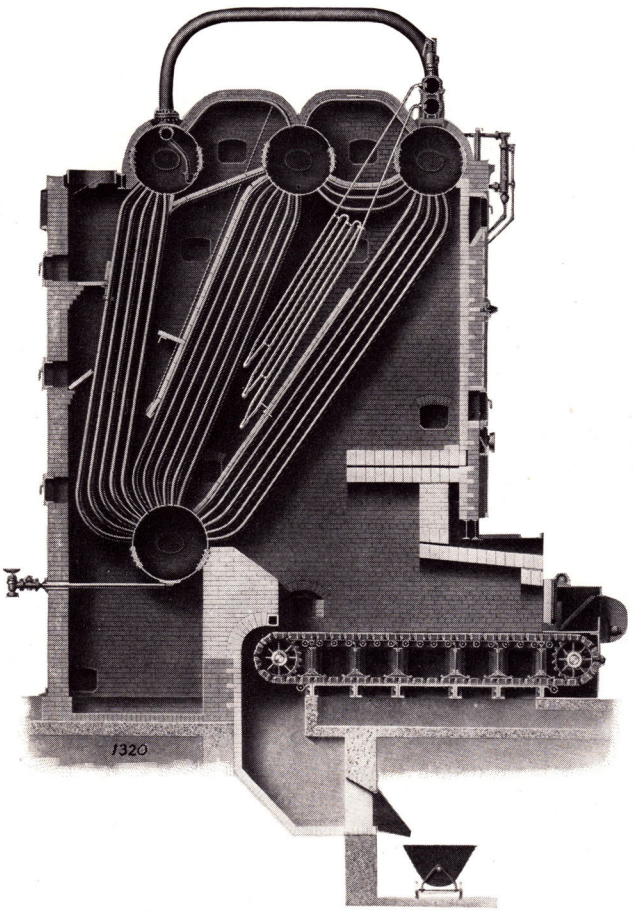

FIG. 9 Elesco Superheater in a Babcock and Wilcox Stirling Boiler.

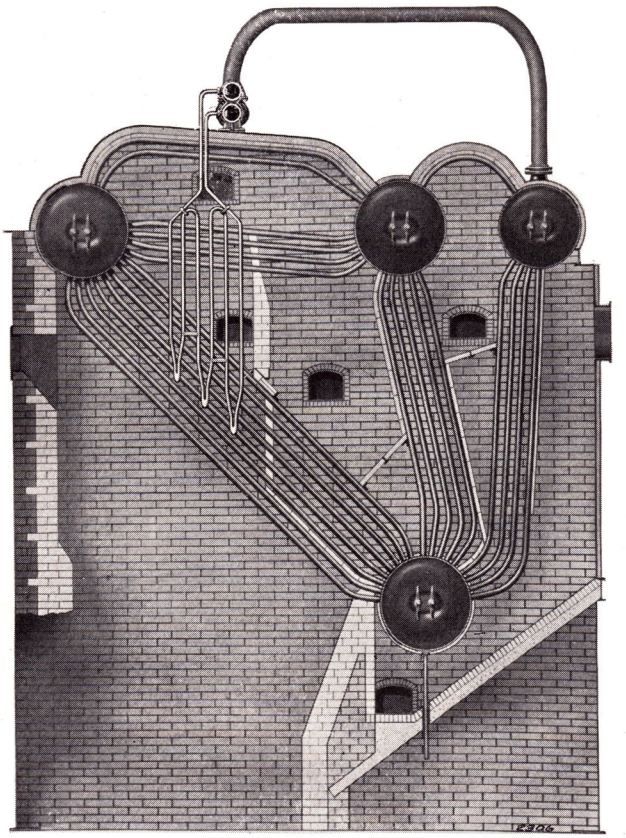

FIG. 10 Elesco Superheater in a Union Iron Works 4-Drum Vertical Bent Tube Boiler.

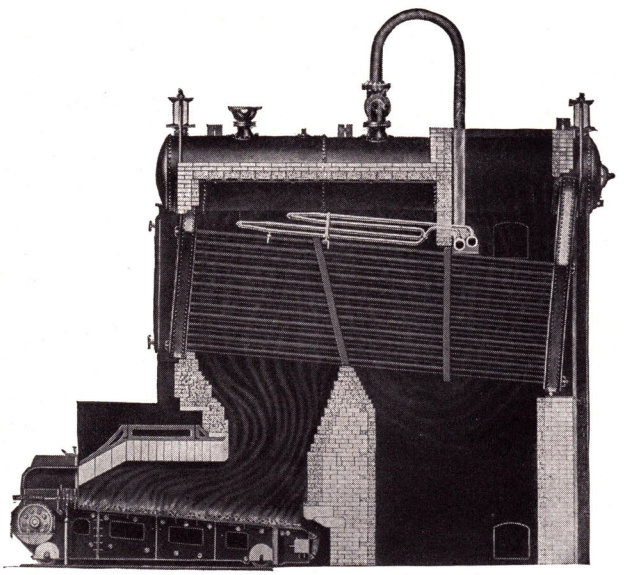

FIG. 11 Convection Type Elesco Superheater in an O'Brien Horizontal Longitudinal Drum Boiler (Vertical Baffles).

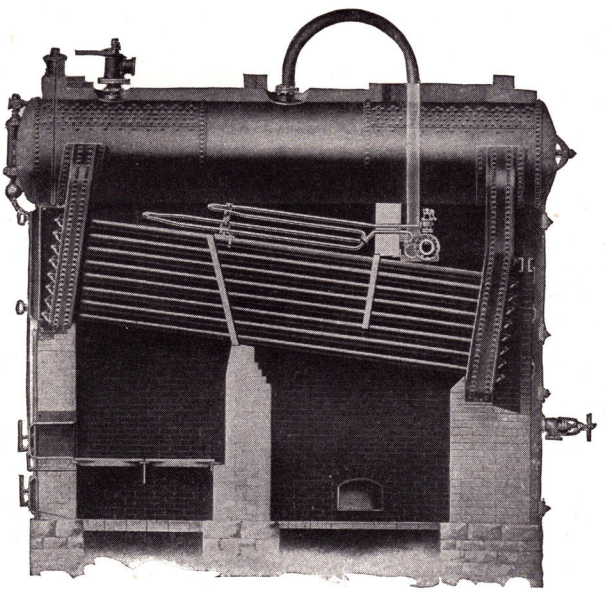

FIG. 12 Convection Type Elesco Superheater in an Oil City Horizontal Longitudinal Drum Boiler.

Superheated Steam

Steam is superheated when it has been heated above the temperature corresponding to the saturation temperature. The temperature difference between superheated steam and saturated steam at the same pressure is known as the degree of superheat.

Steam that is superheated contains no moisture and cannot condense until its temperature has been lowered to that of saturated steam at the same pressure.

Superheated steam is a more efficient medium than saturated steam for transforming heat energy into mechanical energy and, therefore, fuel into power.

How Steam Is Superheated

Steam is superheated by adding heat to it, after the steam is removed from contact with water. Usually the steam is passed through a vessel located in the path of the furnace gases. Sometimes separate sources of heat are employed. Steam may be superheated or reheated in reheaters or steam resuperheaters while passing from the high to the low-pressure stages of large turbines, where the heating agent is live steam. Superheaters with separate furnaces, known as separately fired or portable superheaters, sometimes are employed.

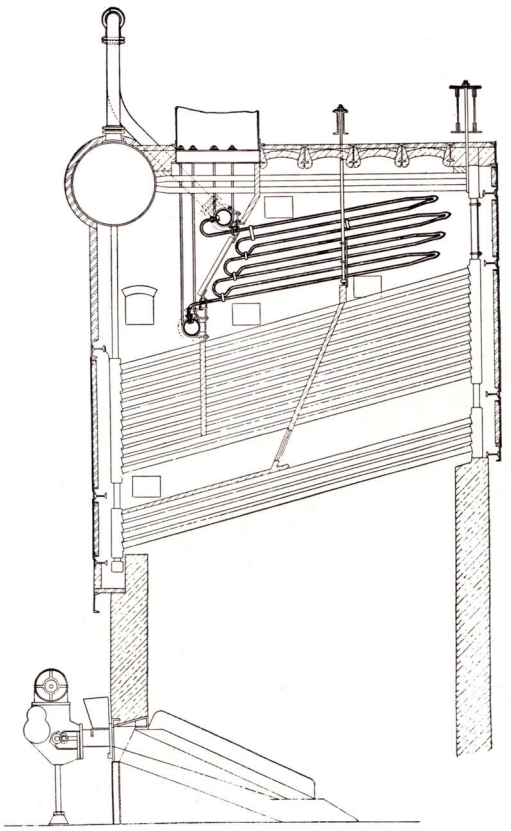

FIG. 13 Convection Type Elesco Superheater in a Connelly Sectional Header Cross Drum Boiler.

Steam can be superheated by throttling. This method, however, is a special instance and is not ordinarily employed, since any degree of obtained superheat is at the expense of reduced pressure.

A Steam Superheater

A steam superheater is an apparatus to increase the temperature of steam without increasing its pressure. It is used generally for raising the temperature of saturated steam direct from a steam boiler. It consists of a system of tubular units or elements with the steam flowing inside and hot gases outside. One end of each tube or unit is connected to a distributor or saturated steam header, the other end to a collector or superheated steam header.

The Elesco superheater consists primarily of:

(1) Two headers of heavy steel pipe, one acting as the distributor for the saturated steam coming from the boiler, and the other for the collection of the steam after it has been superheated and from which the steam is carried to the steam main.

(2) Detachable units of heavy gage, seamless drawn, steel tubing, which are formed by bonding together two or more lengths of tubing by forged return bends. These units are connected to the headers by means of clamped metal-to-metal ball joints.

(3) Connecting pipe between the boiler nozzle and the saturated steam header, outlet flanges, safety valves, drains and gage valves.

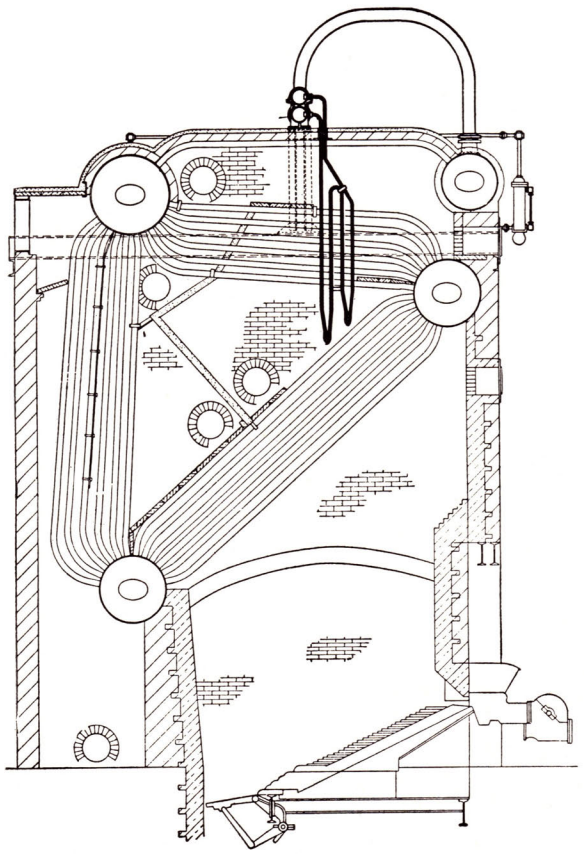

FIG. 14 Elesco Superheater in a Badenhausen Semi-vertical Boiler.

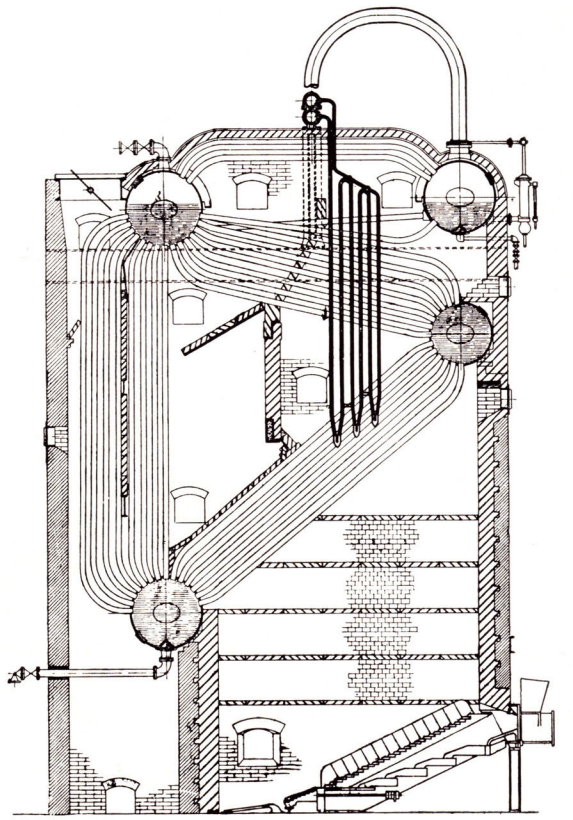

FIG. 15 Elesco Superheater in a Kidwell TU-FLO Ring-Circuit (Semi-vertical) Boiler.

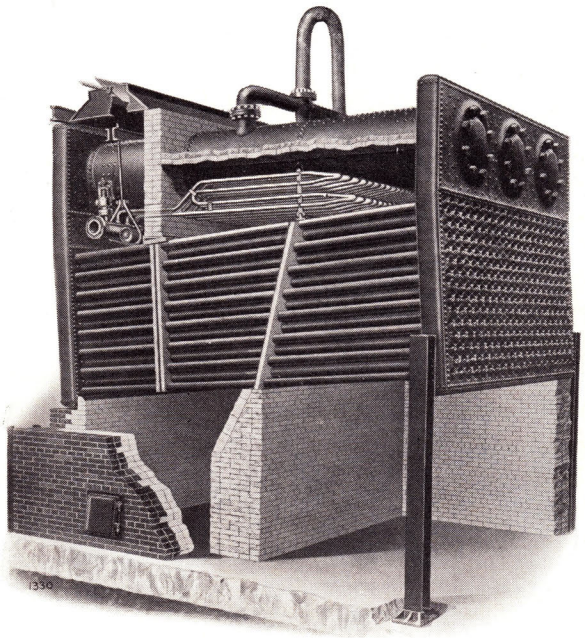

FIG. 16 Convection Type Elesco Superheater in a 3-Pass Edge Moor Horizontal Longitudinal Drum Boiler.

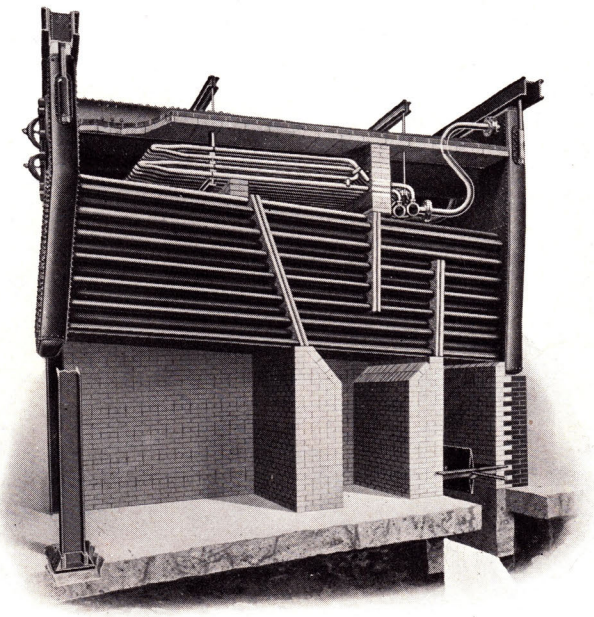

FIG. 17 Convection Type Elesco Superheater in a 4-Pass Edge Moor Horizontal Longitudinal Drum Boiler.

Effect of Superheated Steam

SUPERHEATED steam is a simple and positive means for obtaining a remarkable improvement in the economy of a steam power plant, regardless of what fuel or type of boiler is used for generating the steam. Improvement is manifested in the following five ways:

1. By reducing the steam consumption of the prime mover.
2. By increasing boiler efficiency.
3. By reducing condensation losses in steam lines.
4. By eliminating erosion of steam turbine blades.
5. By increasing the capacity of the plant.

On Steam Consumption

Smaller condensers and smaller auxiliaries are required in a new plant or increased capacity is obtained with existing ones in an old plant.

Table 2, p. 45, shows the approximate steam saving which may be expected, due to the use of superheated steam in various types of prime movers.

On Boiler Efficiency

The overall thermal efficiency of a boiler and superheater combined will be greater than a boiler without a superheater when evaporating the same amount of water; more heat is absorbed, and the final uptake gas temperature is lowered.

Any boiler, therefore, equipped with an Elesco superheater will produce the same power with less fuel than it would without a superheater. This is true either in an existing or in a new plant.

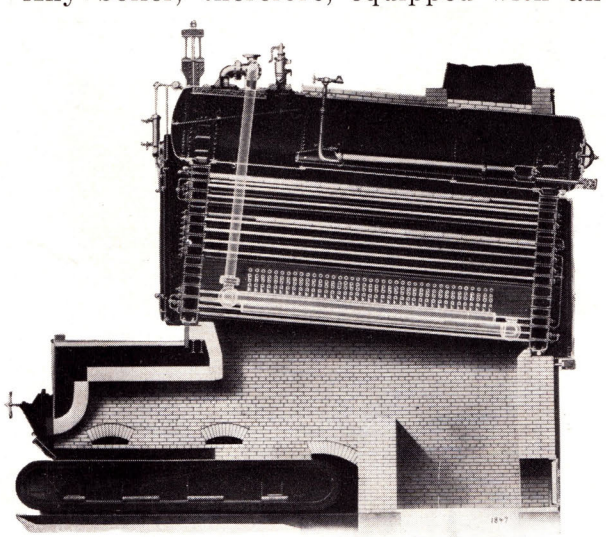

FIG. 18 Interdeck Type Elesco Superheater in a Heine Horizontal Longitudinal Drum Boiler (Horizontal Baffles)

On Steam Transmission

Superheated steam does not give up its heat so readily as does saturated steam. Therefore the radiation losses from a pipe carrying superheated steam are less than from one transmitting saturated steam. With saturated steam, any heat given up by radiation causes part of the steam to condense. This means that the heat which still is contained in the water (condensate) is entirely lost in addition to that heat radiated from the pipe surfaces. By using steam of the proper degree of superheat, no condensation occurs and only that heat which is radiated is lost. An additional advantage, due to the elimination of condensation, is that dry steam and no moisture is delivered to the engine or turbine.

Since steam condensation in piping will be eliminated entirely, less steam need be produced at the boiler. Smaller piping and fewer or no steam traps are required. In an existing plant more steam can be transmitted through the same piping.

Water hammer in piping and water "slugs" entering the prime movers will be eliminated so that a higher steam velocity can safely be used.

On Turbine Performance

In addition to the economy which superheat shows in turbine performance, superheated steam also is instrumental in raising and maintaining the average efficiency and lowering the cost of maintenance. The rapid erosion of turbine blades by moisture in steam is an important factor that has forced the general adoption of superheated steam in turbines. Worn blading increases upkeep and reduces efficiency at an alarming rate.

To Increase Capacity

All the foregoing added together means a greater capacity to an existing plant aside from other economic advantages.

Where superheated steam is used, a smaller amount of boiler evaporating surface is needed to deliver equivalent power. Roughly speaking,

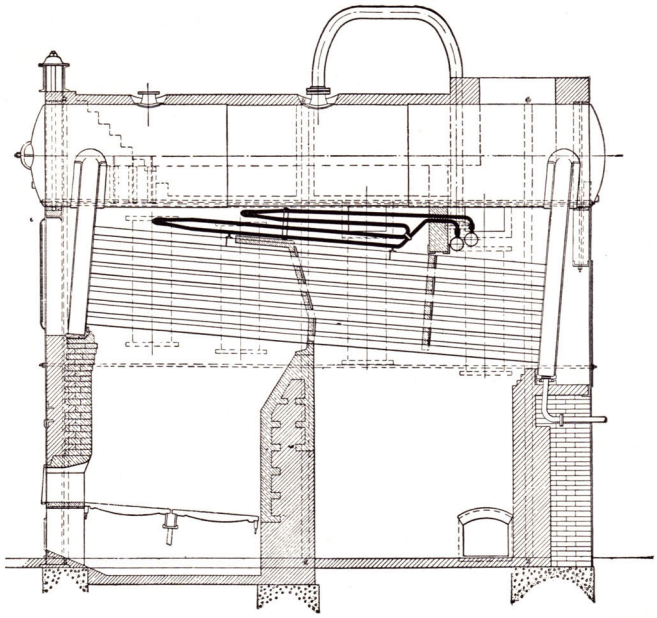

FIG. 19 Convection Type Elesco Superheater in an Erie City Horizontal Longitudinal Drum Boiler (Vertical Baffles).

six boilers equipped with superheaters, furnishing 150 deg. of superheat, will carry the same power load as seven boilers delivering saturated steam. Superheaters are used to advantage, therefore, in taking care of overloads or larger steam requirements at less cost per unit of heating surface than would be possible by installing new boilers. By reason of this fact alone, smaller feed pumps, smaller stacks, smaller coal-handling apparatus and less coal-storage space are sufficient for the demands.

With superheated steam, piping can be reduced in size, because higher steam velocities are permissible. This reduction in pipe size will effect a saving not only in the pipe lines, but also in valves, fittings and covering, and also will reduce radiation losses. In the turbine room, superheated steam will allow the use of a condenser of smaller size than if saturated steam were used. Consequently, smaller circulating water pumps, hotwell and vacuum pumps can be used and minor apparatus, such as steam separators, often can be dispensed with.

These items materially reduce the initial plant cost.

When Operating at Reduced Pressures

It sometimes is necessary, due to deterioration of old boilers, to reduce the operating pressure. This condition results in a loss in plant capacity. Superheating such boilers will enable them to meet the power demands of the plant at the reduced pressure just as well as the boilers did before the pressure was reduced. Furthermore, superheating, in the majority of cases, will provide an additional reserve power over that of the plant before the pressure was reduced.

This is shown by the data in Table 3, p. 47, giving results of tests conducted at a plant having H.R.T. boilers equipped with Elesco superheaters.

Superheaters are so universally recognized as essential that all new stations are applying them; also a large number of the older stations are installing them. These plants include those with boiler capacities as low as 100 hp.

On the Final Results

Because the use of superheated steam decreases the steam consumption of the prime mover and because it increases both the efficiency and the capacity of the boiler, the entire plant efficiency is increased. The final saving from the use of superheated steam due to this increase in efficiency and after all charges such as interest, depreciation, maintenance and operation are accounted for is, in most cases, not less than 10 per cent and frequently more than 25 per cent of the cost of the fuel.

Since superheated steam offers such remarkable returns on a small investment, and since it can be applied to existing plants with such ease, it demands the consideration of those responsible for the economy and operation of steam power plants.

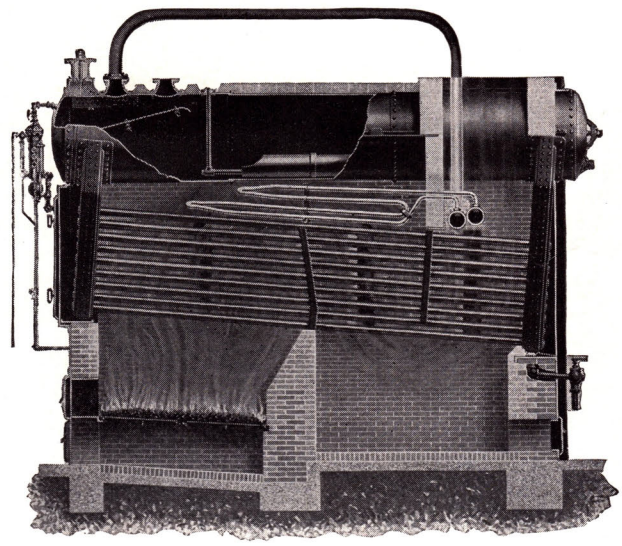

FIG. 20 Convection Type Elesco Superheater in a Kroeschell Horizontal Longitudinal Drum Boiler.

Application of the Elesco Superheater

ELESCO superheaters are adaptable to every make, type and size of steam boiler. They may be installed in an existing boiler without the necessity of making radical changes in the plant.

The superheater is installed as an integral part of the boiler and situated in that part of the boiler setting through which products of combustion pass. It is securely supported, independently of the brickwork where practicable.

Descriptions and illustrations of Elesco superheaters are given in this bulletin for the following types of boilers: water tube boilers of the horizontal longitudinal and cross drum, vertical and semi-vertical types, waste heat boilers and horizontal return tubular boilers.

Convection Type Superheaters for Horizontal Longitudinal and Cross Drum Boilers

Typical applications of convection type Elesco superheaters to horizontal longitudinal and cross drum boilers are shown in Figs. 21 and 22. Other applications are illustrated elsewhere in this bulletin.

For moderate superheats, the superheater is located in the gas path above the first and second passes. This space is ideal for the location of a superheater for moderate temperatures, and sometimes is satisfactory for the higher superheats.

The superheater utilizes the free space left above the baffle to enable the gases to turn from the first pass to the second. Thus the superheater units distribute the flow of the gases evenly over the entire heating surface of the boiler, even at lower ratings.

The superheater units are located above the boiler tubes, close to and parallel to them. They increase in number with the width of the boiler. This permits maintaining the relation between the boiler heating surface and the superheater heating surface; also the relation between boiler heating surface and steam area of the superheater for all sizes of boilers.

The superheat that can be obtained with a certain amount of heating surface depends upon the arrangement and location of the first baffle, since this factor determines the amount of boiler heating surface in the first pass. The

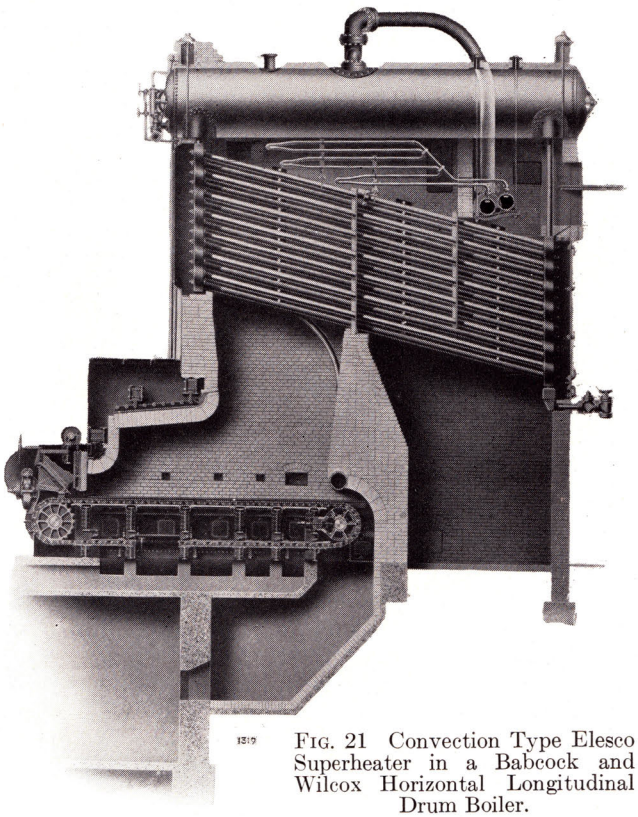

FIG. 21 Convection Type Elesco Superheater in a Babcock and Wilcox Horizontal Longitudinal Drum Boiler.

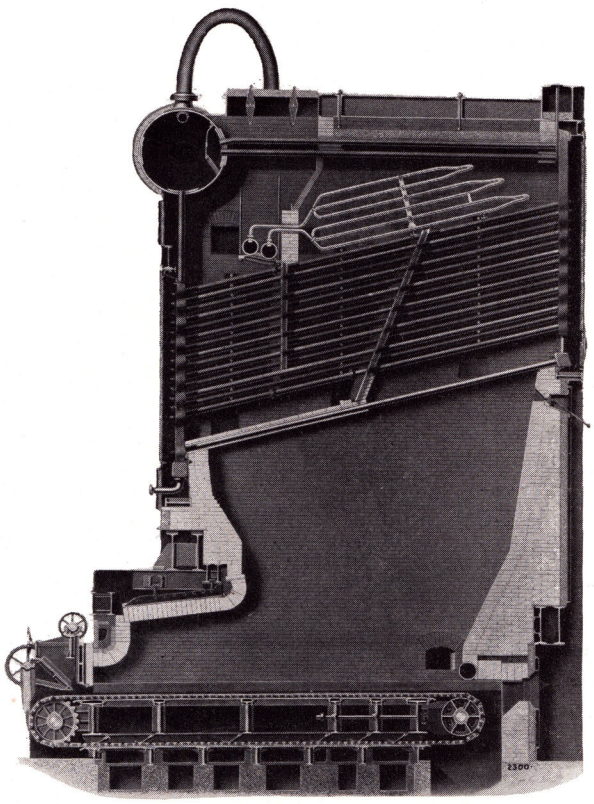

FIG. 22 Convection Type Elesco Superheater in a Babcock and Wilcox Horizontal Cross Drum Boiler.

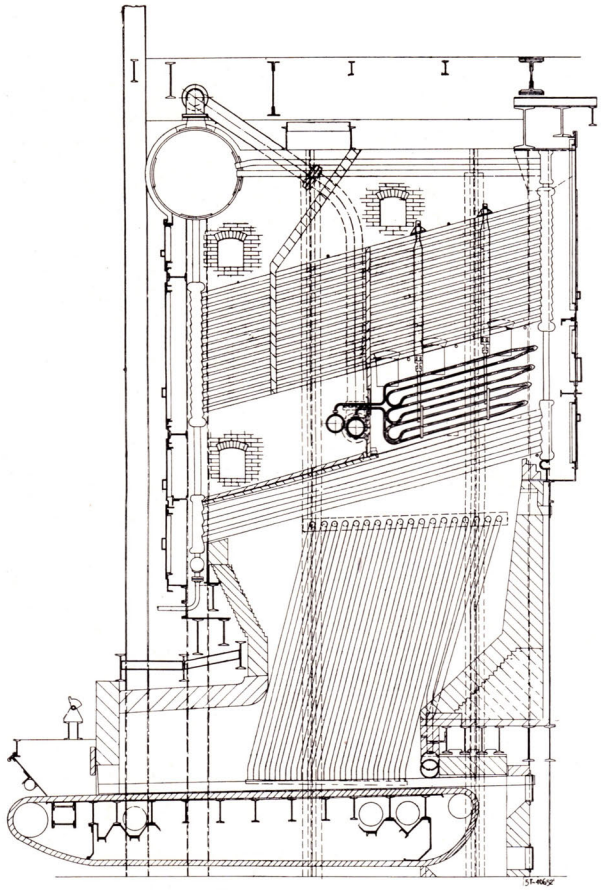

FIG. 23 Interdeck Type Elesco Superheater in a Heine Vertical Forged Steel Sectional Header Horizontal Cross Drum Boiler. Stoker-fired Furnace with Side Water Walls.

smaller the amount of boiler heating surface passed over by the gases before coming in contact with the superheater, the higher is their temperature, and the higher the superheat that can be obtained. With this superheater arrangement the temperature of the steam has a tendency to increase at a higher rating and decrease at a lower rating, due to the change in the amount and velocity of the gases; also due to the change in the velocity of the steam and the temperature of the gases. This slight change of temperature is, however, of little consequence, particularly for moderate superheat.

Interdeck Type Superheaters for Horizontal Boilers

Typical applications of interdeck type Elesco superheaters to horizontal boilers are shown in Figs. 23 and 24.

In order to obtain high superheat with a reasonable amount of heating surface, and to insure fairly constant temperature at different ratings, the superheater is located near the furnace above a shallow bank of tubes. In that bank of tubes most of the steam is generated and heat is absorbed by radiation, as well as by convection. The superheater units thus are subjected to the same fluctuations, so far as the amount and temperature of the gases are concerned, as that part of the boiler. The heat absorption of the boiler and the superheater varies in the same proportion, resulting in constant steam temperatures, irrespective of the amount of steam generated by the boiler.

At the same time, the units are protected from the direct action of the furnace by the lower boiler tubes, so that long life of the units is assured.

The superheater units extend parallel to the boiler tubes, and are located usually in the first pass between the boiler header and first baffle, which affords a high gas velocity and makes the superheater surface very effective.

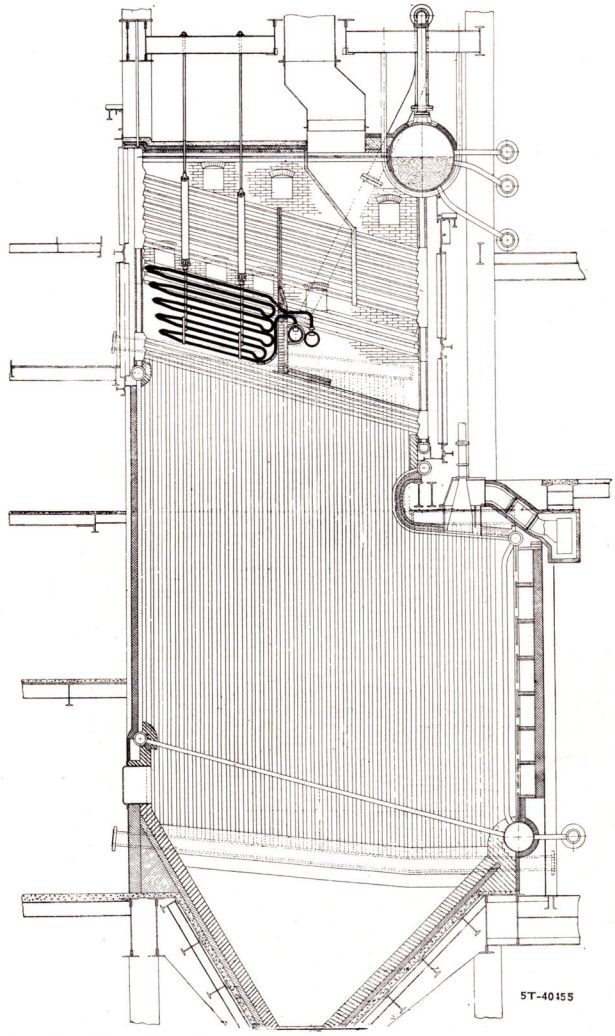

FIG. 24 Interdeck Type Elesco Superheater in a Springfield Sectional Header Cross Drum Boiler. Complete Fin-type Furnace, Fired with Pulverized Fuel.

Radiant Superheaters

Applications of Elesco radiant superheaters are shown in Figs. 25, 26 and 28. A detail of the Elesco radiant superheater behind water-cooled wall is shown in Fig. 29.

Elesco radiant superheaters usually consist of units extending vertically along one or more sides of a furnace behind water-cooled furnace walls. The units are held in position away from the boiler brickwork by high heat-resisting supports and are free to expand and contract without in any way affecting the boiler setting. The headers are outside the setting, which affords ready accessibility to the joints.

These superheaters are exposed to the direct radiant heat of the fuel bed and burning gases in the furnace. By far the biggest part of the heat given up to the superheating surface reaches it by direct radiation and only a comparatively small part is absorbed by convection from the gases. This type of superheater differs materially in a number of respects from the other superheaters described in which all or most of the heat is delivered to the superheater through convection, and therefore involves new problems. Among them is the important one of protecting the superheater against excessive heat of radiation.

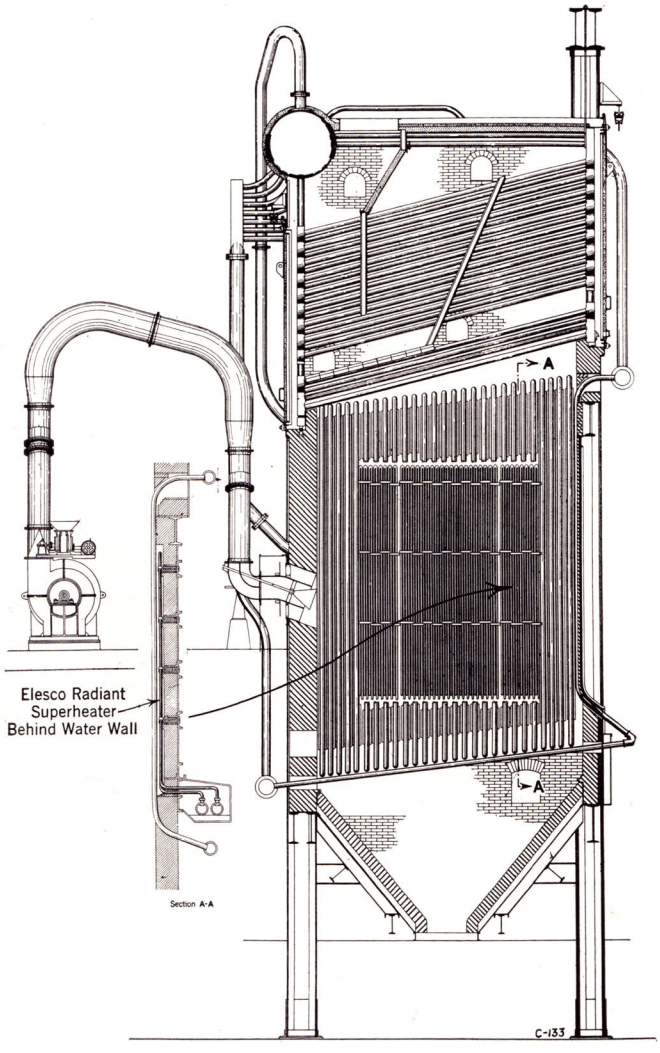

FIG. 25 Elesco Radiant Superheater in a Hedges Walsh Weidner (Walsh and Weidner Type) Forged Steel Sectional Vertical Header Horizontal Cross Drum Boiler.

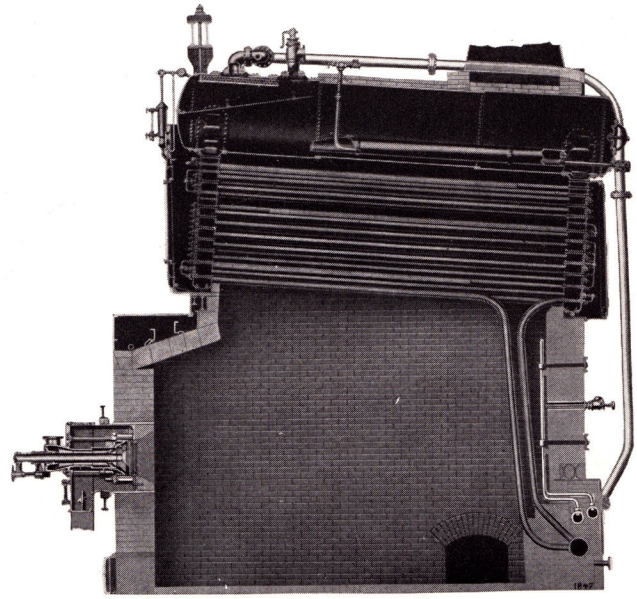

FIG. 26 Elesco Radiant Superheater Behind Water Wall in a Heine Horizontal Longitudinal Drum Boiler (Horizontal Baffles).

In Elesco radiant superheaters, ample protection is provided by arranging a water-tube screen directly in front of and parallel to the superheater units and spaced to give the desired heat absorption. The water tubes afford sufficient protection to insure prolonged life to the superheater units while not shutting off to any appreciable extent the radiation from the furnace. The zone around the superheater is kept at a uniform temperature by the water circulating through the water tubes regardless of any fluctuation of combustion conditions in the furnace.

Sometimes it is necessary to adjust the superheating capacity to meet changes of furnace conditions, as when changing from one type of fuel to another, such as from natural gas to pulverized coal. Adjustment of superheat may be readily obtained with Elesco radiant superheaters by the simple expedient of placing tile between the water wall and the superheater units.

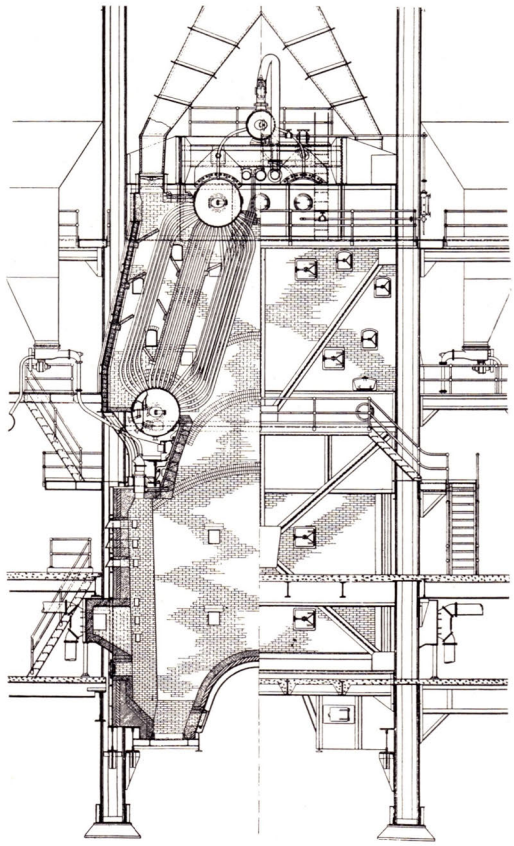

FIG. 27 Sectional Elevation Through Original Ladd Boiler Unit with Elesco Convection Superheater, Fordson Power Plant.

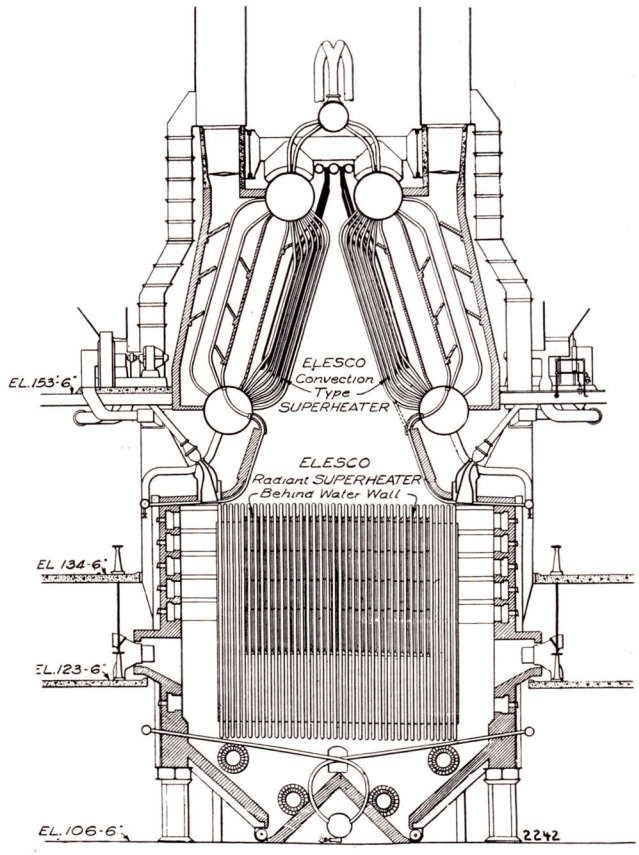

FIG. 28 Sectional Elevation Through Revamped Ladd Boiler Unit, Fordson Power Plant, Showing Enlarged Elesco Convection Superheater and New Elesco Radiant Superheater Behind Water Wall.

Fordson Power Plant, Ford Motor Company, Detroit

The original Fordson Plant, laid out in 1919, was designed for a generating capacity of 65,000 kw. A sectional elevation of the original boiler and furnace layout is shown above at the left. Ultimate capacity was soon raised to 100,000 kw. Then the plant was revamped for an ultimate capacity of 240,000 kw., by revamping the boiler units as shown above at the right.

The original Elesco superheaters of the convection type were retained but increased in capacity. Additional superheating capacity is obtained by Elesco radiant superheaters installed behind a portion of the water wall tubes with which two sides of the furnace have been lined. The radiant superheaters are protected from excessive temperatures by the side wall surfaces, and at the same time, owing to omissions of fins on the side wall tubes at this point, absorb radiant heat from the furnace.

An unusual feature is that the side wall cooling surfaces and the water screen at the bottom of the furnace are arranged in two complete circulating systems independent of the boiler proper. The drums on either side of the furnace receive and supply feed water to both side wall and water screen tubes. The steam generated in these heating surfaces is returned to the drums, passed through the Elesco radiant superheater, from which it is delivered to the main steam header.

Thus by arranging side water walls, water screen at bottom of furnace and radiant superheaters into independent circulating systems delivering steam into the main header, and by increasing the capacity of the original Elesco convection superheaters, operation at over 600 per cent rating is made possible as compared to 250 to 300 per cent in the former installation.

The following table gives

DATA ON CHANGES

	Original	Revamped
Make of boilers	Ladd Double	Semi-vertical
Number of boilers	8	4
Boiler horsepower	2,647	2,647
Average rating per cent	250	625
Average lb. of steam per hour	200,000	500,000
Type of water wall	None	Fin Tube
Radiant heating surface in side walls, sq. ft.	None	1,554
Total water heating surface, sq. ft.	26,470	29,494
Total superheating surface, sq. ft.	3,140	4,620
Method of firing	Pulv. Coal and Blast Furnace Gas	
Pressure, lb. per sq. in.	260	260
Superheat, deg. F	200	270
Final temp., deg. F	610	680

One of the best adaptations of this type of superheater is to furnaces where considerable dust is carried over in suspension and which is liable to lodge on the heating surfaces. With the superheater along the furnace walls the boiler tubes are more accessible for cleaning. While the superheater units are out of the direct path of the gases and do not easily become coated, they may be kept clean by the application of regular soot blower equipment, as shown in Fig. 29. If desired, the protecting water wall tubes can also be cleaned with the same blowers. Elesco radiant superheaters will therefore give the same superheat constantly, under the same combustion conditions, since soot or slag formations may be removed without taking the boiler off the line.

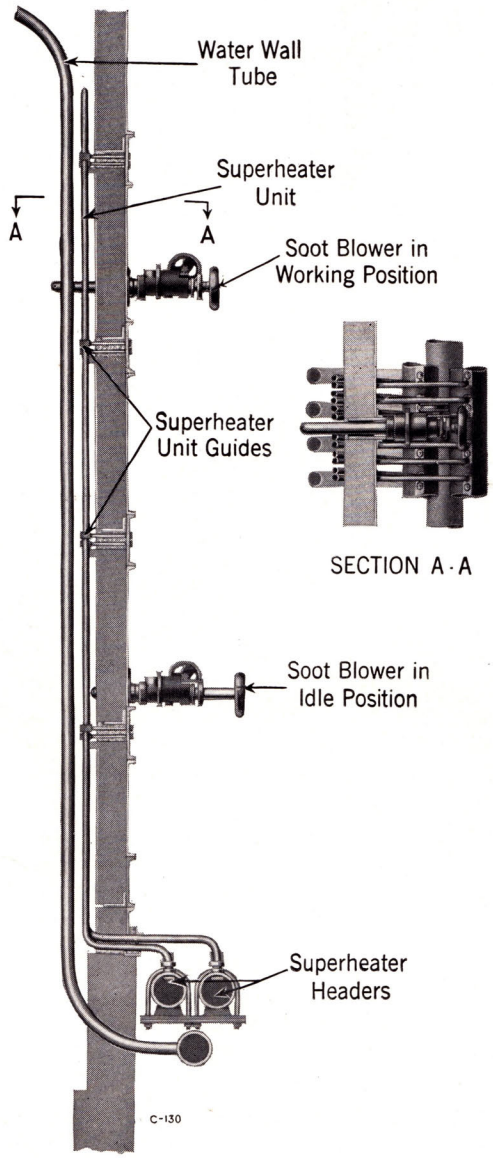

FIG. 29 Detail of Elesco Radiant Superheater Behind Water-cooled Wall with Soot Blowers.

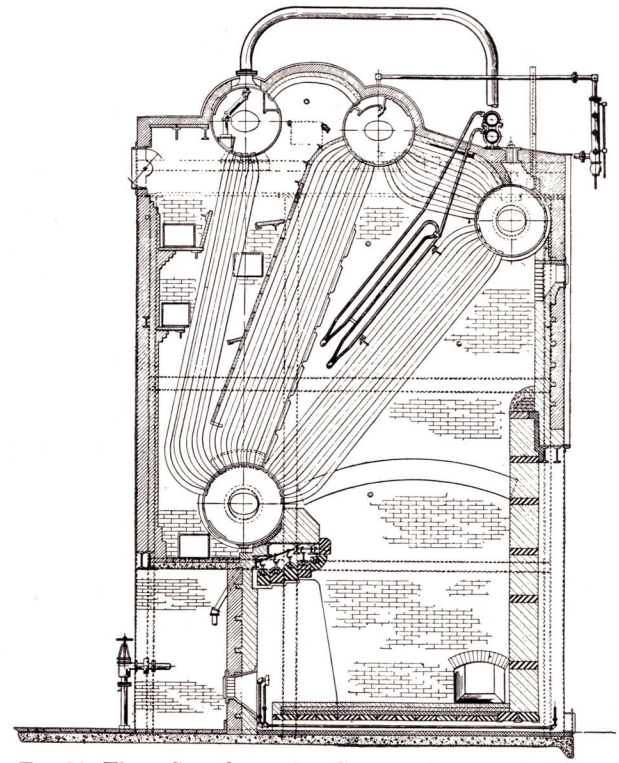

FIG. 30 Elesco Superheater in a Connelly Semi-vertical Boiler.

Superheaters for Semi-vertical Boilers

Various arrangements of Elesco superheaters for semi-vertical boilers are shown in Figs. 27, 28, 30, 33, 34 and 36.

In designing Elesco superheaters for this type of boiler, consideration was given to the problem of obtaining a standard design and location that would be capable of delivering moderate as well as the higher degrees of superheat; a uniform temperature for all ratings. In many of the semi-vertical boilers the superheater units therefore are placed between the boiler tubes of the first pass, as in Figs. 27, 28 and 34, where they are subjected to the same variation in temperature and quantity of the gases as that part of the boiler in which most of the steam is generated. The fact, also, that a small part of the superheater is exposed to radiant heat tends to hold down the superheat at higher ratings, resulting in a nearly constant superheat at all boiler loads.

The units, being located between the boiler tubes, break up the flow of the gases, so that they come in better contact with the boiler tubes. The gas streams are diverted just as in

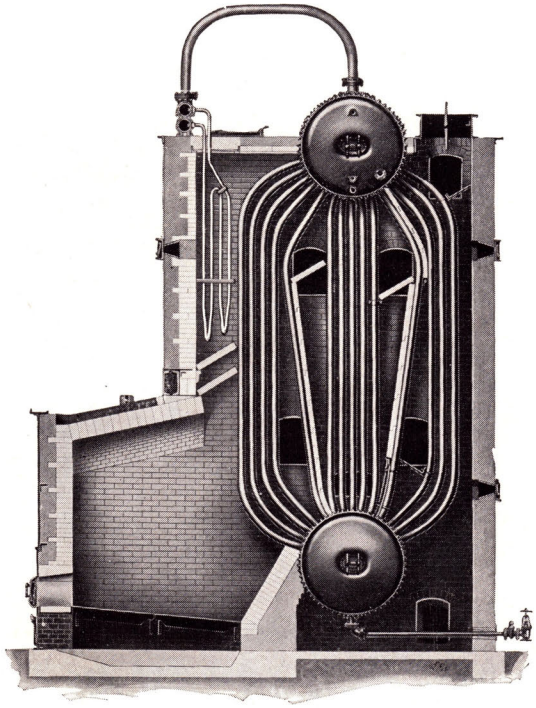

FIG. 31 Elesco Superheater in a Hedges Walsh Weidner (Casey-Hedges Type) Vertical Boiler.

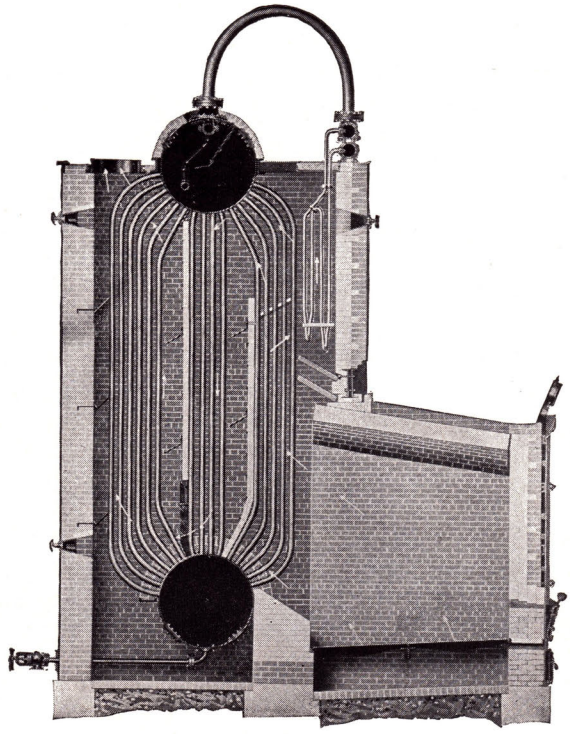

FIG. 32 Elesco Superheater in an Erie City Vertical Boiler.

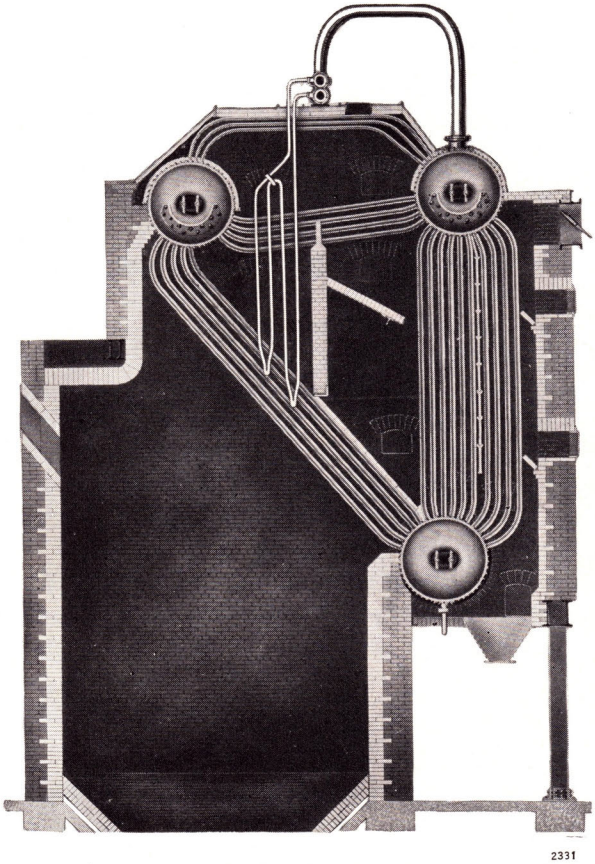

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FIG. 33 Elesco Superheater (Vertical Type) in a Wickes 3-Drum Curved Tube Boiler with Pulverized Fuel Furnace.

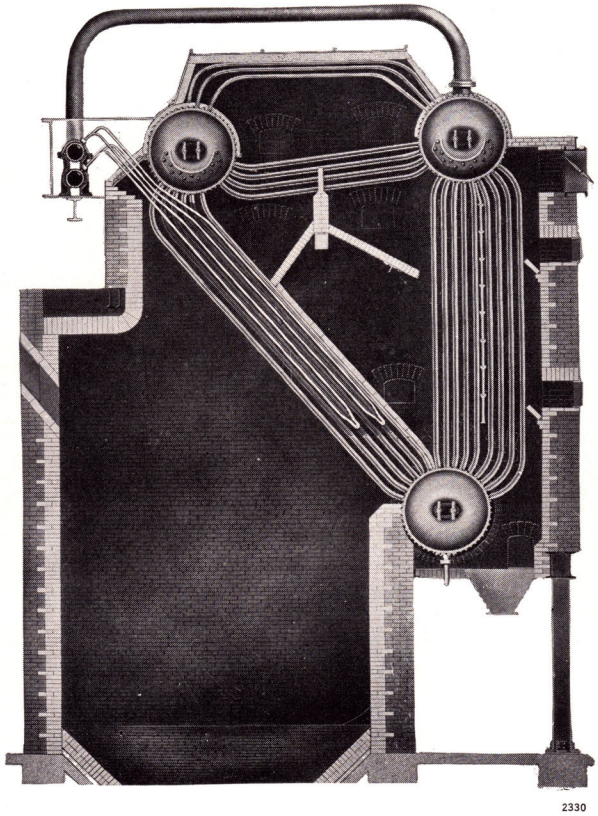

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FIG. 34 Elesco Superheater in First Tube Bank of a Wickes 3-Drum Curved Tube Boiler with Pulverized Fuel Furnace.

the staggered tube arrangement of horizontal boilers, and the heat transfer from gases to boiler tubes is materially increased. This results in a lower exit gas temperature and correspondingly higher boiler efficiency.

In some types of semi-vertical boilers, as in Fig. 30, the triangular space between the first and second banks of tubes is utilized by the superheater for moderate superheats, while in other types the temperature of the gases in this location is sufficient to obtain a high superheat with a reasonable amount of heating surface. When a baffle is located in front of the superheater the gases are prevented from by-passing the second pass bank of tubes and thus the efficiency of this pass is increased. The exit gas temperature is thereby decreased and the efficiency of the boiler increased.

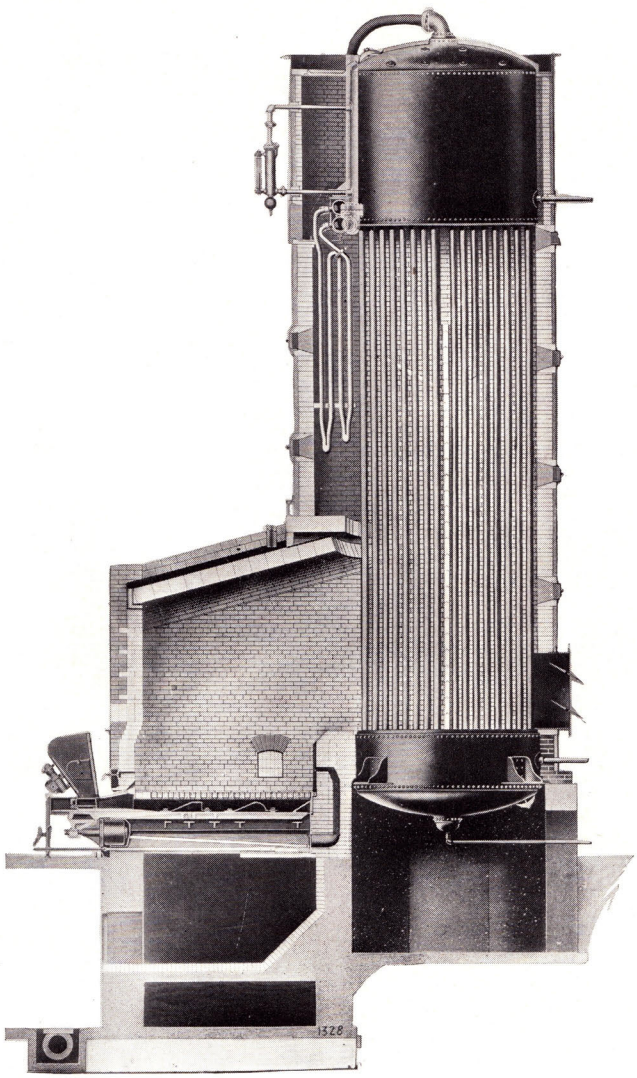

FIG. 35 Elesco Superheater in a Wickes Vertical Boiler.

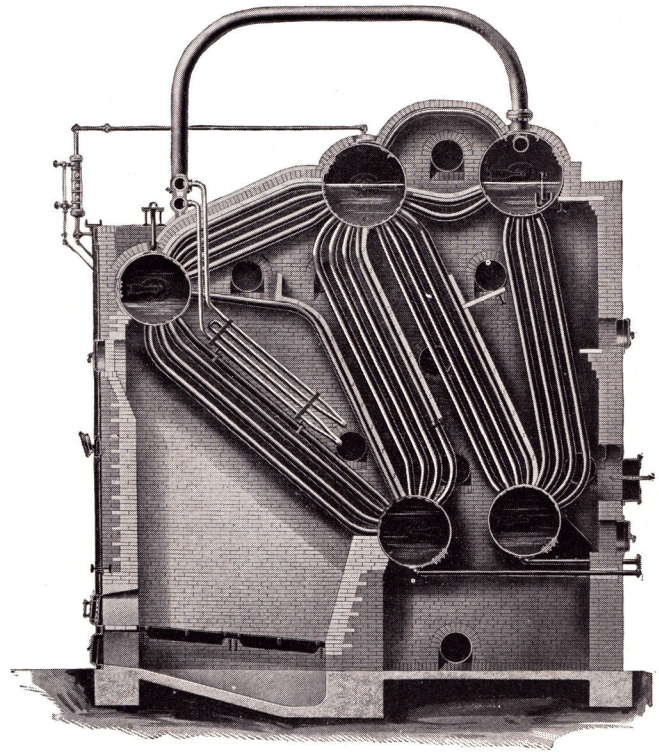

FIG. 36 Elesco Superheater in a Hedges Walsh Weidner (Casey-Hedges Type) Multipass Boiler.

In other types of semi-vertical boilers the superheater units extend down vertically through the roof and through the upper bank of boiler tubes into the free space between the upper and lower banks of tubes, as in Fig. 33. For high superheat they extend further into the lower bank where the gas temperature is high.

With this superheater design, an additional advantage is taken of the Elesco return bends, which have thickened walls where the hot gases impinge on them, thus adding to the protection of the units at the place where it is most required. The vertical position of the units makes it possible to suspend them from the headers or from steel work above the boiler without additional weight on the boiler tubes.

In all superheater arrangements for semi-vertical boilers the units extend down through the top of the boiler. They extend down between the circulating tubes either into the tube bank, in which case they are so spaced that there is no restriction in gas area through the boiler tubes, or they extend into the gas area between the first and second tube banks adjacent to the furnace.

The soot cleaning problem also is made easy, as the smooth sloping surfaces of the superheater units are easily cleaned.

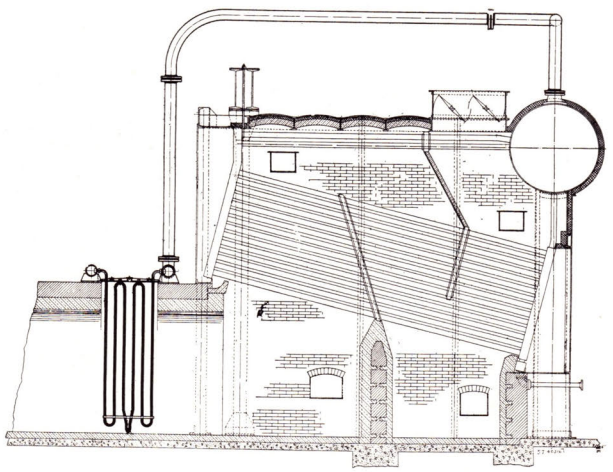

FIG. 37 Elesco Superheater in a Hedges Walsh Weidner (Walsh and Weidner Type) Horizontal Cross Drum Waste Heat Boiler.

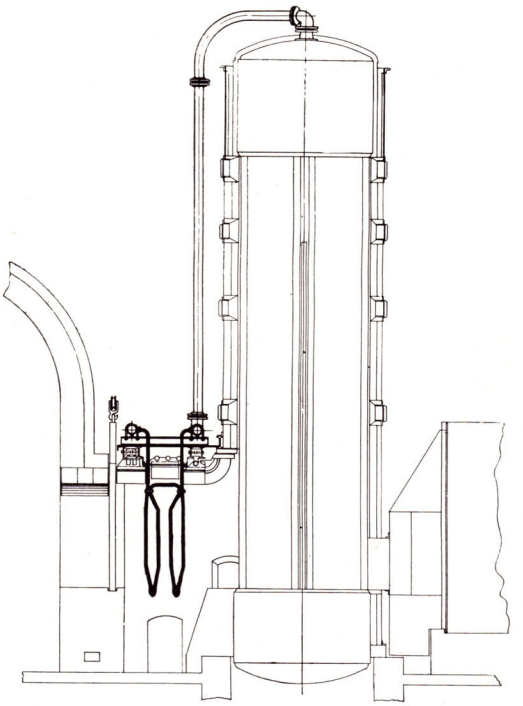

FIG. 38 Elesco Superheater in a Wickes Vertical Waste Heat Boiler.

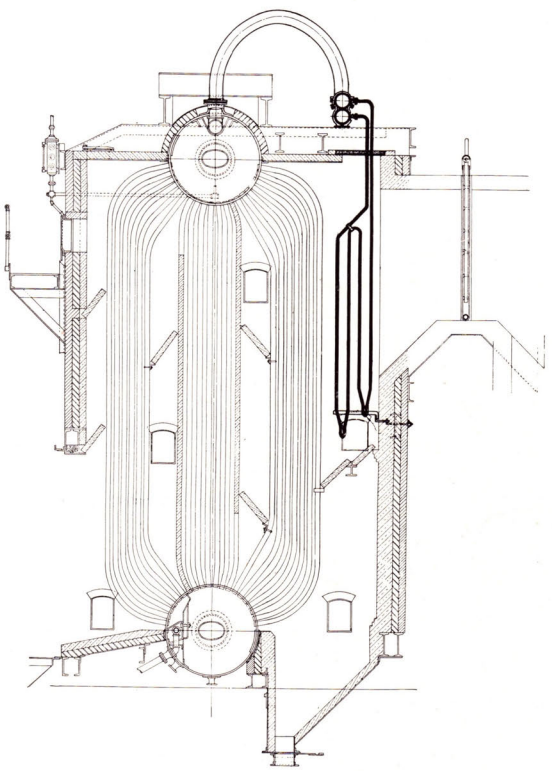

FIG. 39 Elesco Superheater in a Ladd Vertical Waste Heat Boiler.

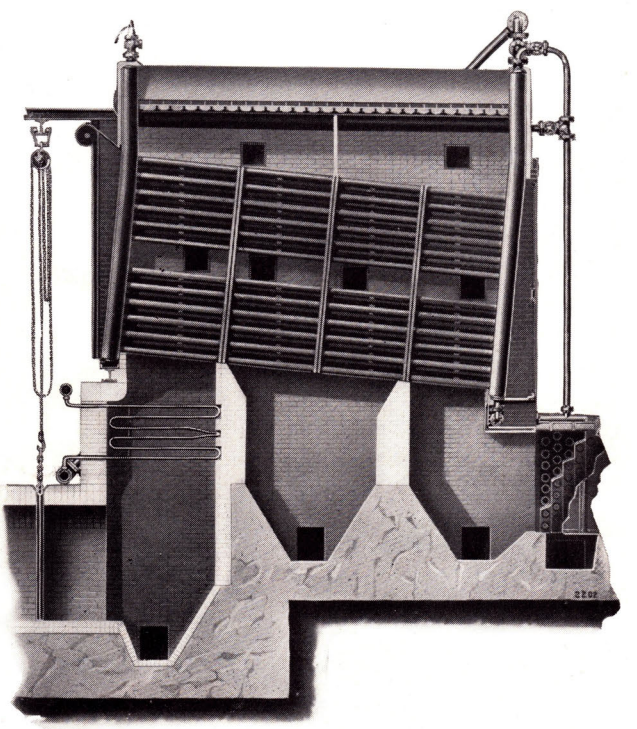

FIG. 40 Elesco Superheater in an Edge Moor Waste Heat Boiler.

Superheaters for Vertical Boilers

Arrangements of Elesco superheaters in vertical boilers are shown in Figs. 31, 32 and 35.

Elesco superheaters may be installed in vertical boilers without disturbing the boiler setting except in very special cases.

In two-drum boilers the superheater units are located either in the space between the first bank and the front wall or between the boiler tubes of the first bank. When located between the first bank and the front wall they are protected by two rows of tiles below the superheater so staggered as to form partial baffles and and to force the hot gases through the boiler tubes before passing over the superheater, thus protecting the units from the direct flame of the furnace. By placing the baffles closer together or farther apart the degree of superheat can be easily regulated.

Where there is a Dutch oven, as in Figs. 31 and 32, the arch extending toward the boiler tubes protects the units from the direct flames.

With Elesco superheaters for vertical boilers the gases flow upward along the units. An additional advantage is taken of the Elesco forged return bends, which have thickened walls where the hottest gases impinge on them, thus adding to the protection of the units at the place where it is most required.

In some makes of vertical boilers the headers and joints are located outside on top of the boiler setting and the units extend down through the roof.

In large boilers of this type, as shown in Fig. 35, if the standard superheater were used where all the units are arranged in a straight line, most of the units would be at a considerable distance from the boiler tubes which are arranged in a circle and the space between the tubes and the superheater units would be wasted. Hence the headers are bent so that the units are located nearer to the boiler tubes.

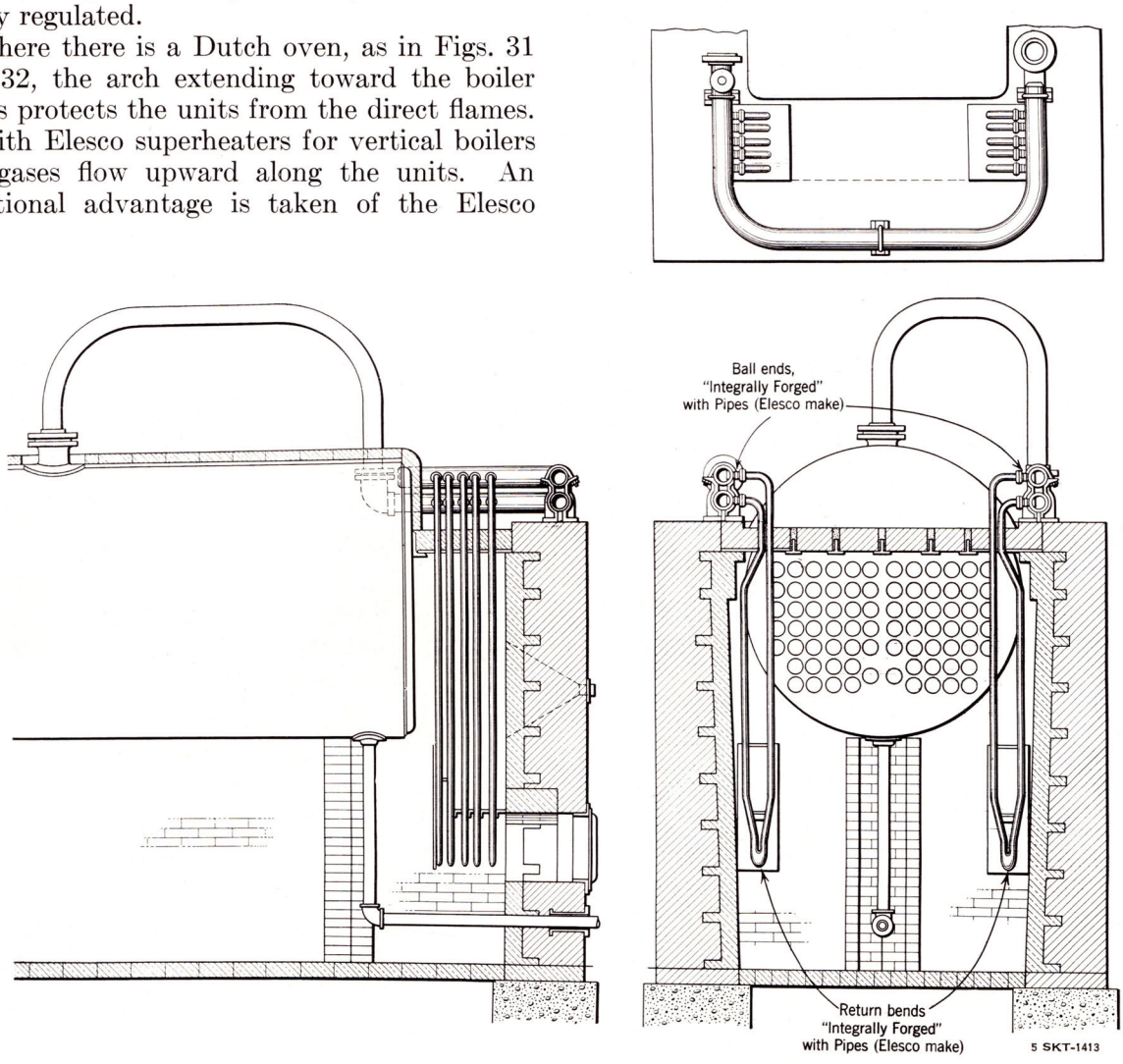

Fig. 41 Elesco Superheater in an H.R.T. Boiler (Bent Header Design).

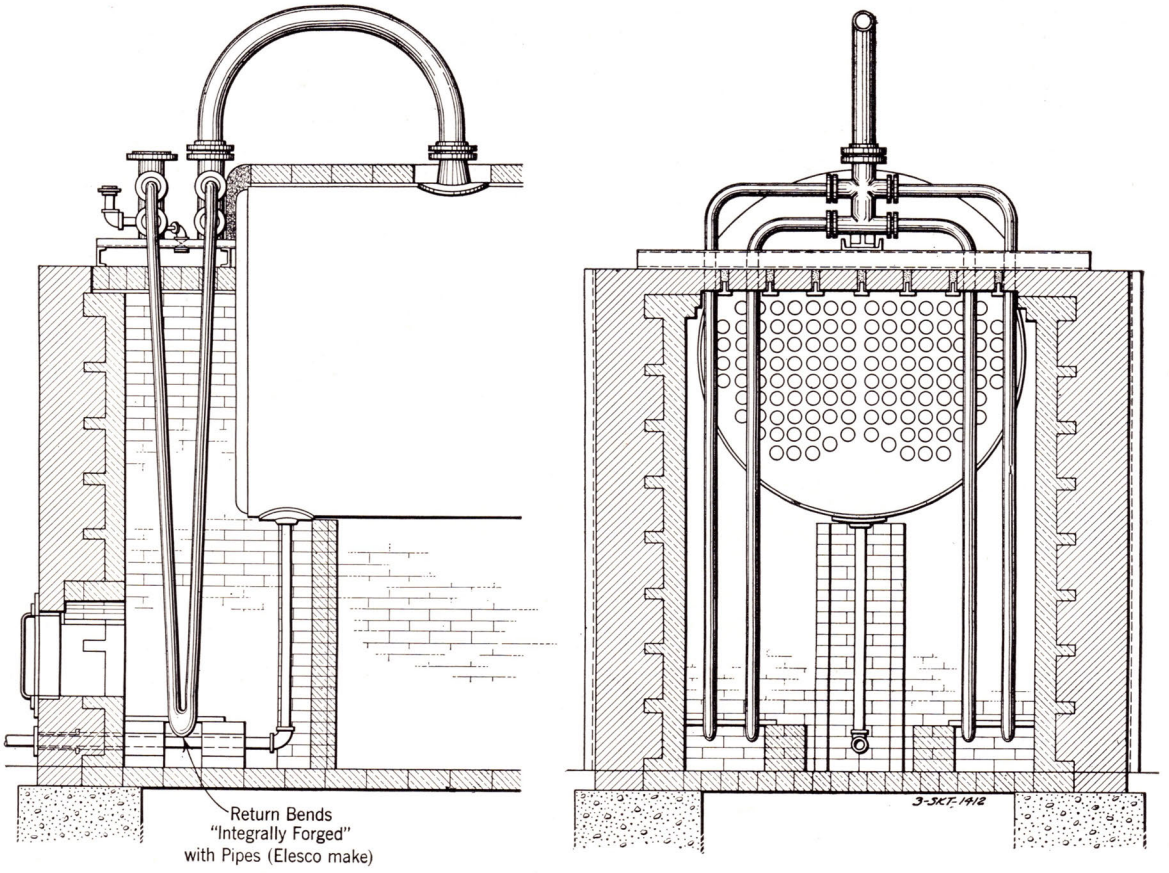

FIG. 42 Elesco Superheater Arrangement for Small H.R.T. Boilers.

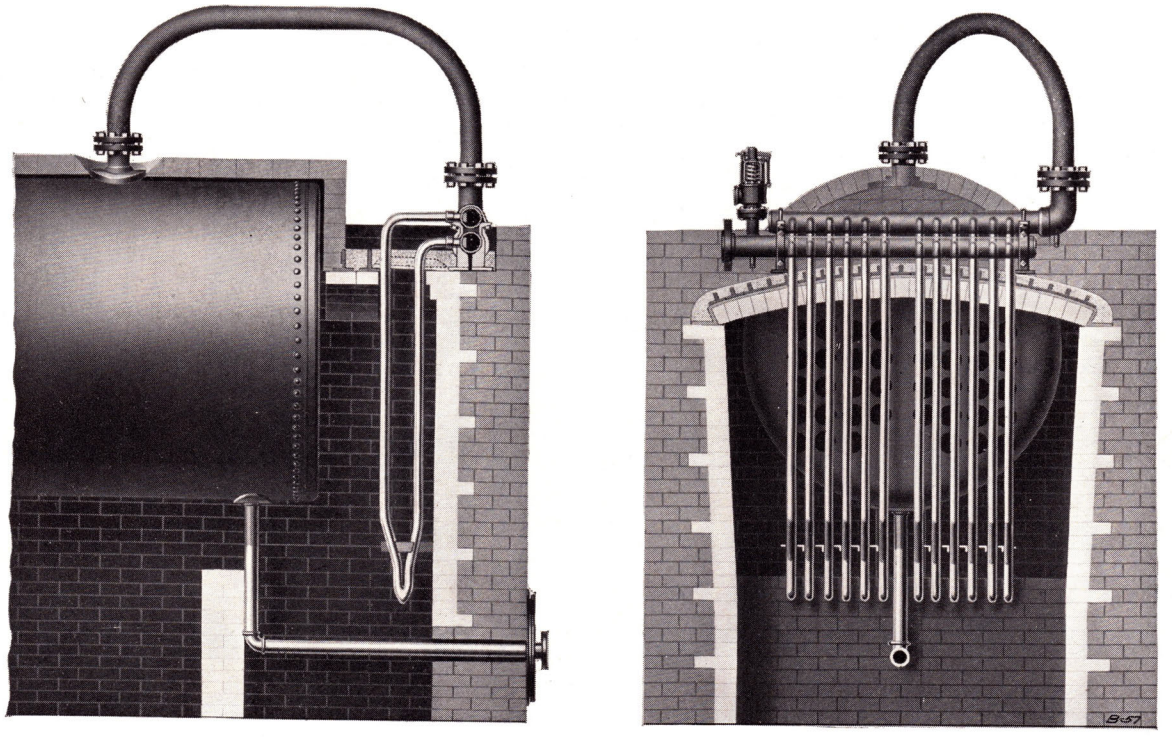

FIG. 43 Elesco Superheater in an H.R.T. Boiler (Standard Arrangement).

Superheaters for Waste Heat Boilers

In waste heat boilers for cement mills utilizing waste gases from rotary kilns, and in boilers connected with open-hearth furnaces or in similar installations where the temperature of the waste heat gases is not above 1400 to 1500 deg., the superheater is located before the boiler or in the duct carrying the gases to the boiler. A comparatively small superheater is required in this location, due to the high temperature difference between the gases and the steam, so the pressure drop of the steam flowing through the units as well as the draft loss of the gases are relatively low. Wherever possible, the superheater units are placed in the vertical position as shown in Figs. 37, 38 and 39.

Where waste gases with temperatures higher than 1400 to 1500 deg. are available for the boiler, the superheaters are placed in the same location as in boilers having their own furnaces.

The fact that Elesco units offer the least resistance to the flow of the gases is of considerable importance in connection with waste heat boilers where any draft loss should be avoided and where the gases frequently contain soot and ashes.

Superheaters for H.R.T. Boilers

A part of the combustion chamber at the rear of the boiler is utilized for the superheater. The temperature of the gases in this location is sufficient to obtain any desired superheat with a reasonable amount of heating surface. The vertical position of the superheater units keeps them clean and free from soot or ashes, and makes it possible to suspend the units from the outside of the boiler. This arrangement also provides ample space for the inspection and maintenance of the boiler tubes at this end of the boiler.

Depending upon conditions, the units are located either along the rear wall or along the side walls in the rear combustion chamber. In the first or standard arrangement, as shown in Fig. 43, the headers are straight and are located along the top of the rear wall. In the second arrangement the headers are bent and are arranged, in general, as shown in Fig. 41.

For smaller horizontal return tubular boilers, due to the small amount of steam, only a few units are required. They are located on each side of the boiler near the wall of the combustion chamber, and are connected to two single or double *T's*, one for the saturated steam, the other for superheated steam. This arrangement is shown on Fig. 42.

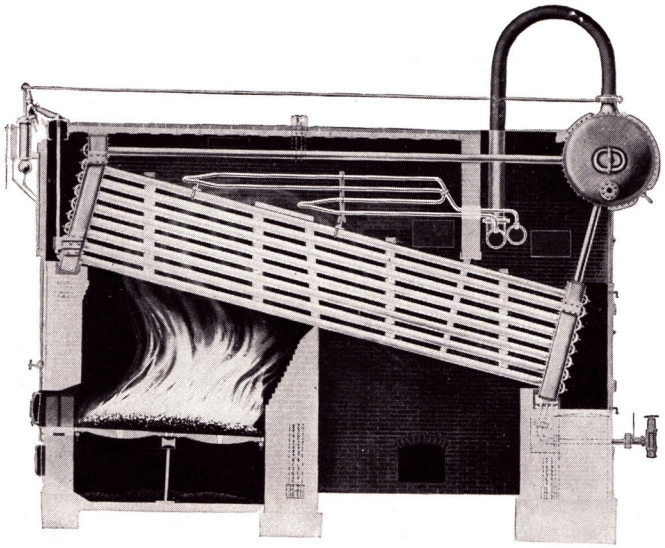

FIG. 44 Convection Type Elesco Superheater in a Keeler Horizontal Cross Drum Boiler.

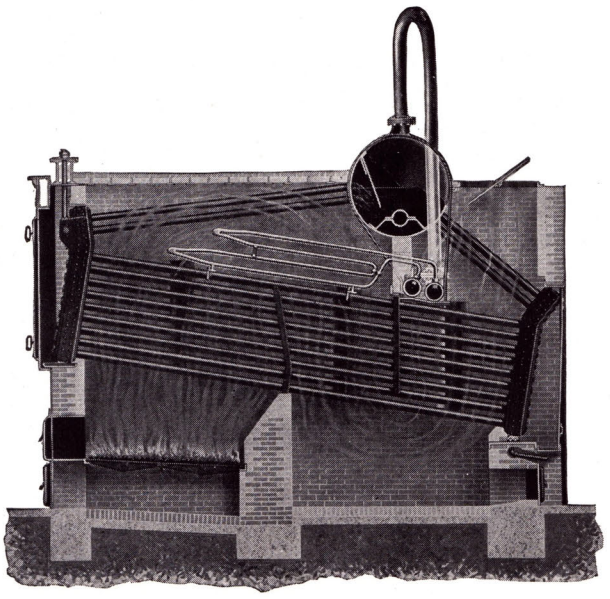

FIG. 45 Convection Type Elesco Superheater in a Kroeschell Horizontal Cross Drum Boiler

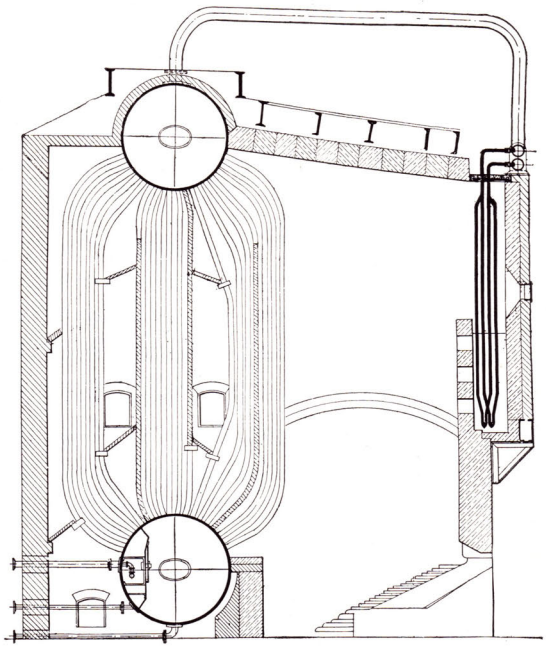

FIG. 46 Elesco Superheater in a Ladd Vertical Boiler with High Arch Setting.

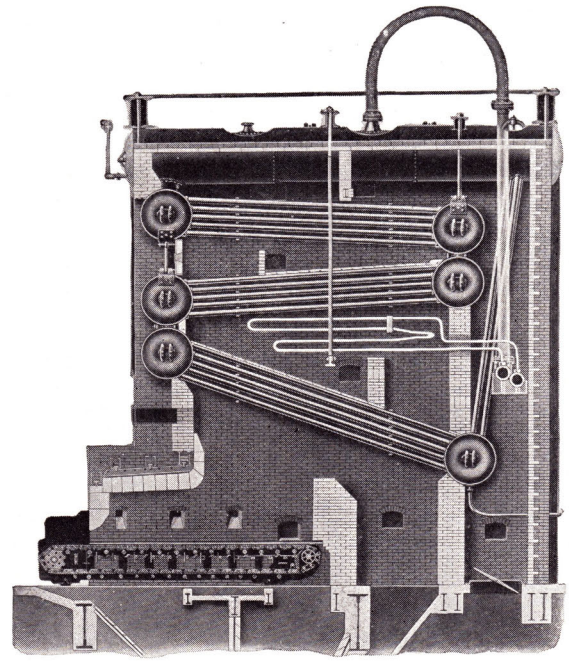

FIG. 47 Convection Type Elesco Superheater in a Vogt Horizontal (Class H-5) Boiler.

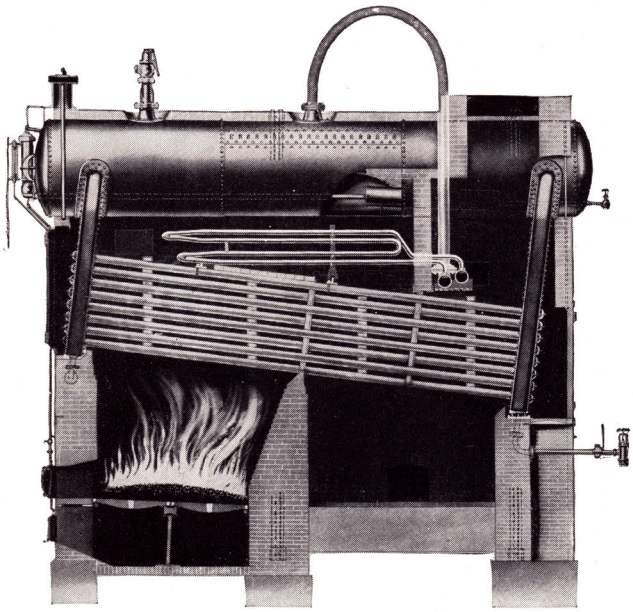

FIG. 48 Convection Type Elesco Superheater in a Keeler Horizontal Longitudinal Drum Boiler.

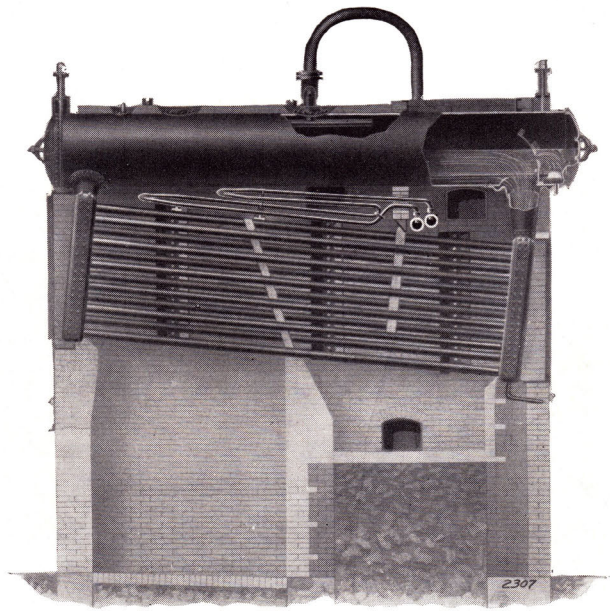

FIG. 49 Convection Type Elesco Superheater in a Union Iron Works Horizontal Longitudinal Drum Boiler.

Advantages of the Elesco Superheater

WHILE the economies accruing from superheated steam are very important, there is perhaps no piece of boiler room apparatus which gives less trouble than a properly designed superheater.

In the development of a superheater for stationary boilers, there are a number of points which should be ever present in the mind of the designer. The following generally are accepted as essential requirements and are the principles on which the Elesco superheater is based:

1. Improved overall efficiency of the boiler and superheater combined.
2. Maximum superheater efficiency.
3. Uniformity of superheat.
4. Safety and security of operation.
5. Complete accessibility for inspection and maintenance.
6. Freedom from soot deposits.
7. Minimum draft loss.
8. Protection against overheating, insuring long life by uniform distribution of steam through all units under all load conditions, positively preventing any by-passing of steam.
9. Use of high steam velocities for maintaining clean interior surfaces and maximum heat transfer with minimum pressure drop.
10. Minimum possibility for leaks.
11. Flexibility and adaptability to any design of boiler.
12. First cost consistent with results.

How the above requirements are satisfied by the Elesco superheater is explained in detail below.

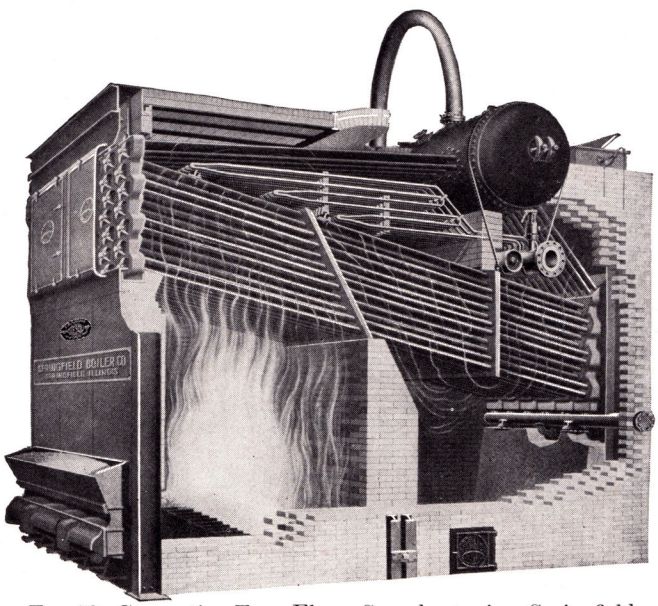

FIG. 50 Convection Type Elesco Superheater in a Springfield Standard Sectional Horizontal Cross Drum Boiler. The Shape and Spacing of the Units Can Be Regulated So as to Fit Into the Space Available and Provide a Large Proportion of Superheating Surface.

Improved Overall Efficiency of the Boiler and Superheater Combined

By the introduction of the additional heating surface of the superheater in a boiler setting or steam generating system a greater total heat absorption is effected with a resultant increased overall efficiency. In most types of boilers, Elesco superheaters are installed in such a manner as to compel the gases, after passing the superheater, to flow past some of the water evaporating surface. Such a location is advantageous because the temperature of the steam, after being superheated, is higher than that of the water. Therefore the gas temperature on leaving the superheater will be higher than that at the boiler uptake.

Maximum Superheater Efficiency

The Elesco superheater gives higher efficiency for several reasons.

First—Large Proportion of Superheating Surface

The units are made of small diameter tubing, which gives a large superheating surface in proportion to the cross-sectional area of the *steam* path, as illustrated in Fig. 50.

The steam being evenly distributed in the units through a long lineal passage makes possible large proportions of heating surface. The design of the units embodying Elesco features enables the designer to arrive at the exact proportion of heating surface that will give the amount of superheat required under given conditions.

Second—Located in Advantageous Position

The outside diameter of the units is small and they can be made of any desired length or form, so it is possible to place them in the most advantageous location with reference to the gas path. This also permits the disposition of the units in locations which will tend to distribute the flow of the gases more evenly through the boiler and increase the absorption of heat from the gases.

This advantage of the Elesco superheater is demonstrated by many superheater arrangements shown throughout this bulletin.

Third—Proper Distribution of Gases

In designing Elesco superheaters extreme care is exercised in placing the units so that they are swept evenly by all the gases of combustion; the same gases which pass over the boiler surfaces also traverse the superheating surfaces. Because the units comprise small diameter tubes the mean distance of the particles of gas from the heating surface is kept at a minimum and more heat is therefore absorbed by the superheater units. This means maximum efficiency of heat transfer from the gases to the steam without reducing the capacity of the boiler. Only in this way can this high efficiency be obtained.

While the units are arranged so as to split up the gases and proportion them evenly in their flow past the superheating surfaces, the use of small diameter tubing for superheater units avoids any undue draft loss at high boiler capacities. This is demonstrated graphically in Fig. 51. These illustrations show a comparison between a superheater with large diameter tubing and one with small diameter tubing. It is apparent that, where the units are of small tubing and are staggered, there is an even distribution of gases and likewise low draft loss. Fig. 53 shows a typical arrangement of Elesco superheater units in the tube bank of a semi-vertical boiler.

Even distribution of gases also gives the least opportunity for adhesion of dust and soot; consequently a constant high rate of heat transfer and high uniform superheat is maintained.

Fourth—Uniform Distribution of Steam Through Units

The inlets and outlets of the headers are on opposite sides of the setting, which insures uniform distribution of steam to all units at all loads, as illustrated diagrammatically in Fig. 54. The units, being of small diameter tubing having a uniform area throughout their length, cause even distribution of the steam over a greater lineal surface. This even distribution of the steam throughout the entire superheater is a vital factor in obtaining high efficiency.

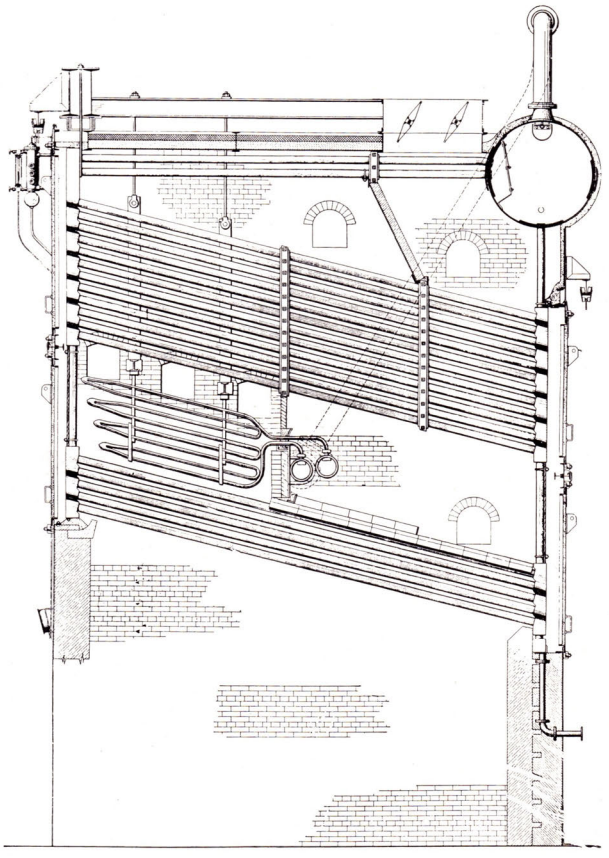

FIG. 52 Interdeck Type Elesco Superheater in a Hedges Walsh Weidner (Walsh and Weidner Type) Forged Steel Sectional Vertical Header Horizontal Cross Drum Boiler.

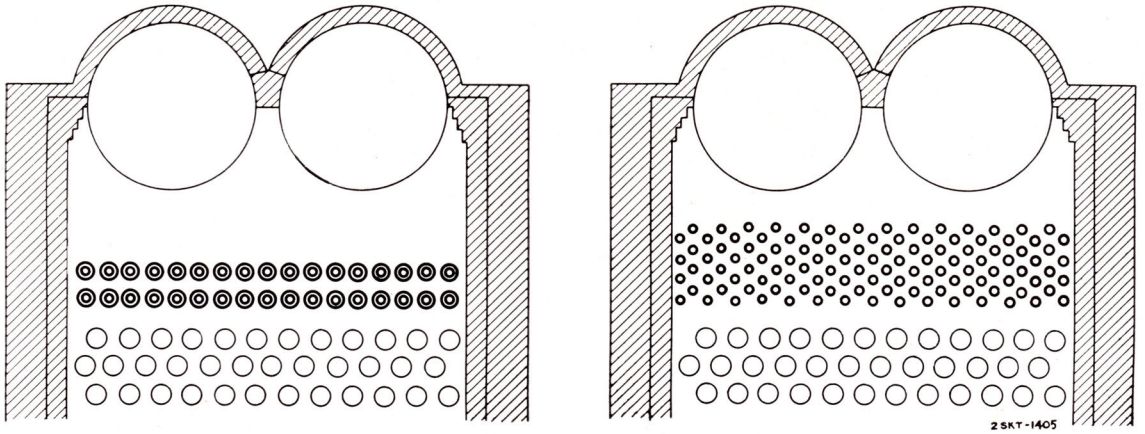

FIG. 51 Comparison of Gas Area in Horizontal Boiler Through Small Tube Superheater (Right) and Large Tube Superheater (Left)

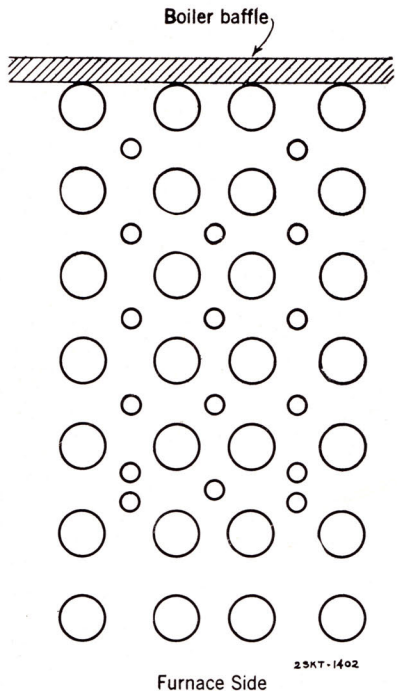

FIG. 53 Typical Arrangement of Elesco Superheater Units in Tube Bank of Semi-vertical Boiler.

Fifth—High Efficiency in Heat Transfer

As the steam is brought into intimate contact with the gas-touched heating surface, a minimum resistance to the flow of heat from the gases to the steam is obtained. This feature of the Elesco superheater deserves serious consideration. The comparatively low specific heat of superheated steam and its small heat-absorbing capacity as compared with water makes the consideration of the steam-touched surface a subject of paramount importance.

The small diameter tubing used in Elesco superheaters gives large internal heating surface, or a large ratio of steam-touched to gas-touched surface.

As tubing diameters decrease, the proportion of cross-sectional area to the inside heating surface increases, thereby causing more steam to come in contact with the heating surface.

The following comparison demonstrates the decrease in the ratio of steam area to internal heating surface as the tubing diameter is increased:

	No. 10 B.w.g. Tubing	
	1½-in. O.D.	2-in. O.D.
Internal heating surface per foot	0.3225 sq. ft. or 46.44 sq. in.	0.4534 sq. ft. or 65.29 sq. in.
Steam area	1.192 sq. in.	2.356 sq. in.
Ratio of area to internal heating surface	38.96	27.71

Because this ratio is large and because every particle of steam is brought into intimate contact with every part of the steam-touched surface, while all the gas-touched surface is in contact with the gases, unusually high efficiency is shown in the transfer of heat from the gases to the steam.

Uniformity of Superheat

In designing an Elesco superheater, particular stress is laid on obtaining a superheat with minimum variation of temperature, or constant superheat, independently of the load on the boiler and without sacrificing the simplicity or practicability of the installation. The super-

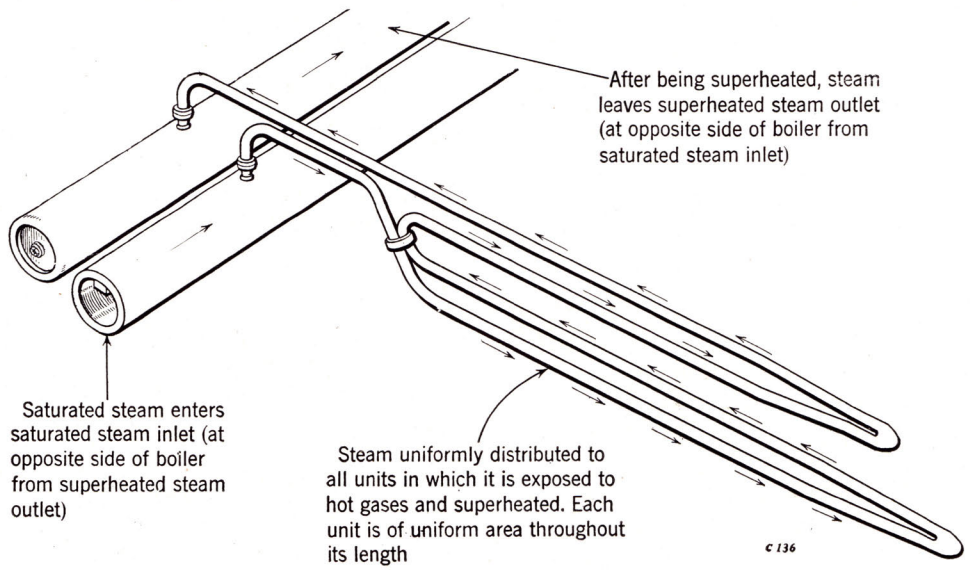
After being superheated, steam leaves superheated steam outlet (at opposite side of boiler from saturated steam inlet)
Saturated steam enters saturated steam inlet (at opposite side of boiler from superheated steam outlet)
Steam uniformly distributed to all units in which it is exposed to hot gases and superheated. Each unit is of uniform area throughout its length
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FIG. 54 Diagram of an Elesco Superheater.

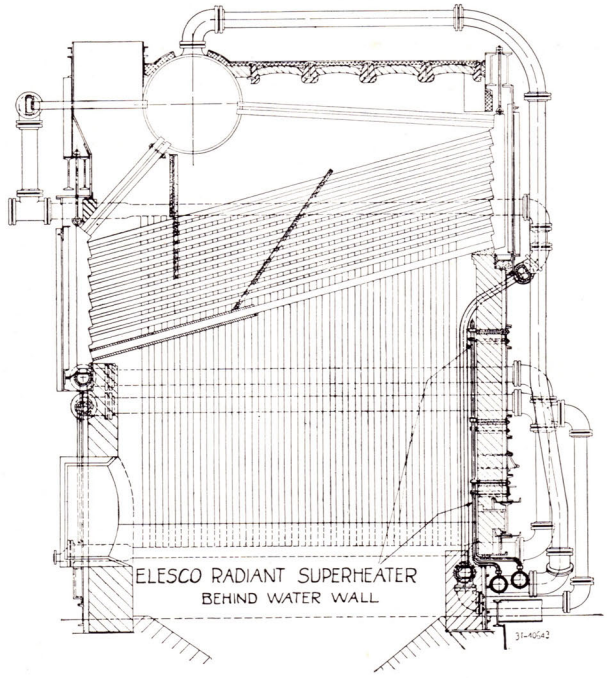

FIG. 55 Elesco Radiant Superheater in a Springfield Standard Sectional Horizontal Cross Drum Boiler.

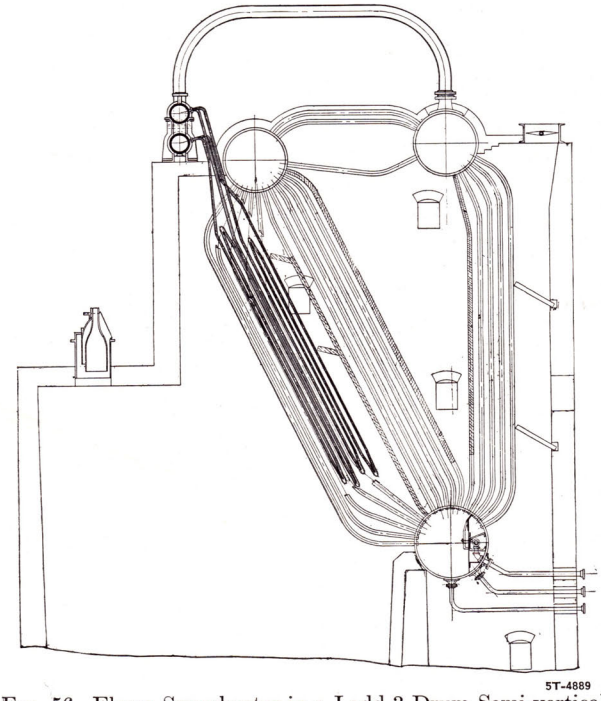

FIG. 56 Elesco Superheater in a Ladd 3-Drum Semi-vertical Boiler.

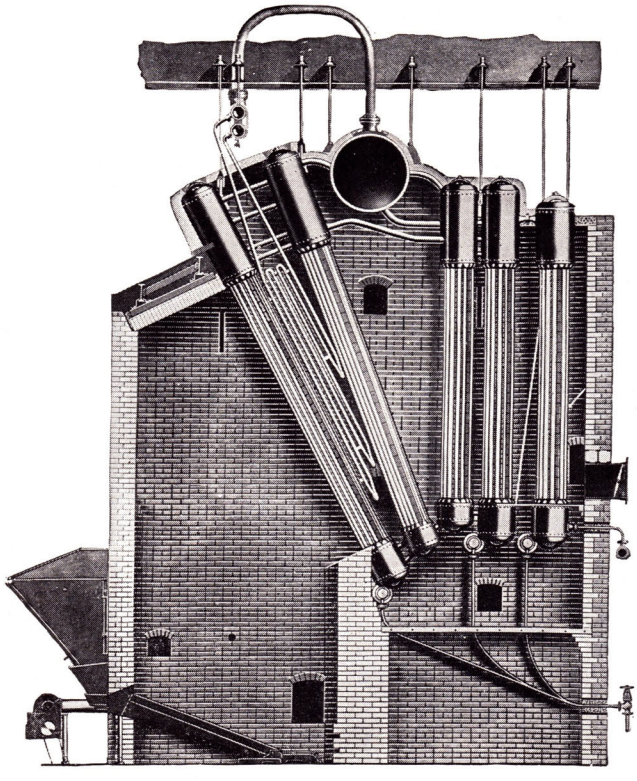

FIG. 57 Elesco Superheater Between First and Second Rows of Units of a Bigelow-Hornsby Semi-vertical (Five Deep) Boiler with a Single Bank Integral Steel Economizer. This Arrangement of Elesco Superheater Is for Very High Superheat.

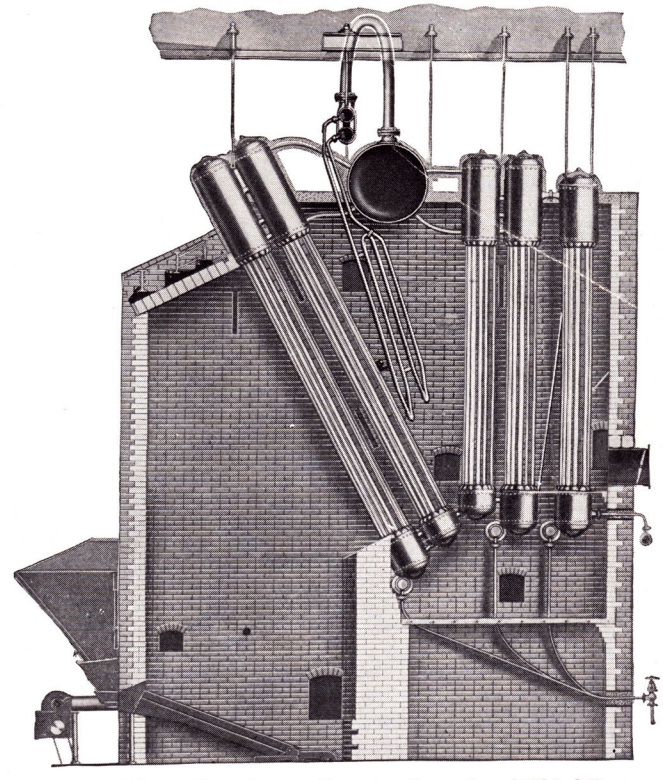

FIG. 58 Elesco Superheater Between Second and Third Rows of Units of a Bigelow-Hornsby Semi-vertical (Five Deep) Boiler with a Single Bank Integral Steel Economizer. This Arrangement of Elesco Superheater Is for Moderate Superheat.

heater units are so located in the boiler that the heat absorption of the boiler and the superheater maintain an approximately constant relation. That is, the quantity and heat content of the gases in the superheater space vary in direct proportion to the quantity of steam generated; therefore an approximately uniform steam temperature is maintained. In applying this principle to horizontal and semi-vertical boilers, for the higher superheats, the superheater units are located between the boiler tubes, and very close to the furnace so that the superheater absorbs heat by radiation as well as by convection. Typical Elesco superheater arrangements of this type are shown in Figs. 52, 56, 61 and 64.

Uniformity is further assured by the fact that the units present a smooth surface, thereby

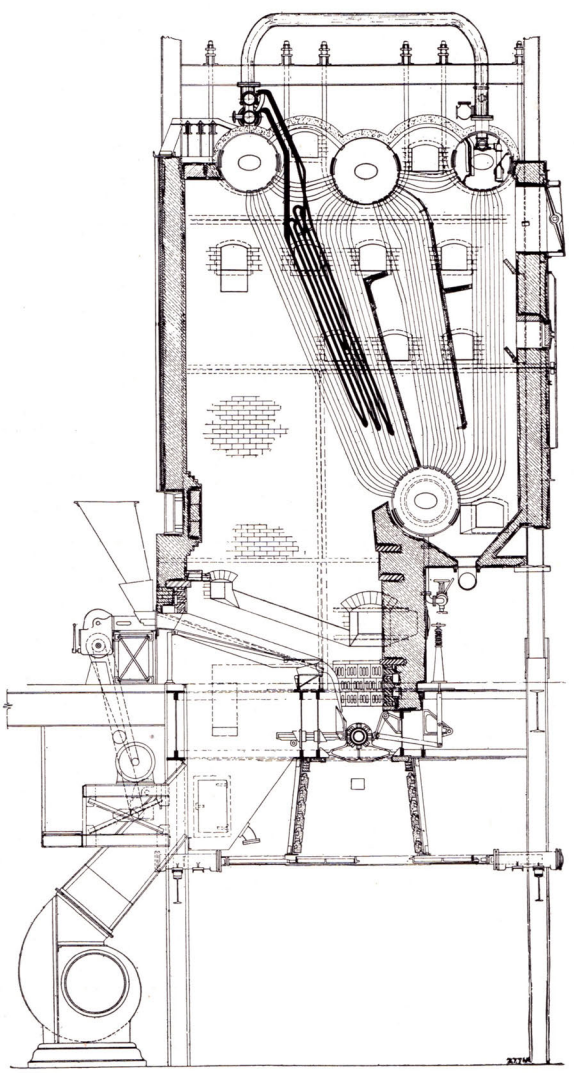

FIG. 59 Elesco Superheater in a Heine V-type Boiler.

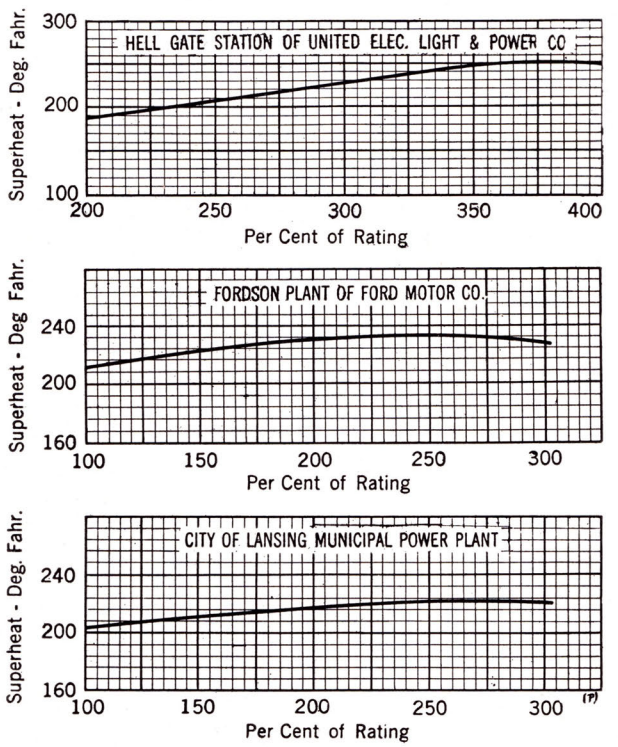

FIG. 60 Curves Showing Superheat Maintained at Three Prominent Stations Equipped with Elesco Superheaters.

minimizing the collection of soot and ashes on them. Also most careful consideration is given to individual conditions of furnaces, fuels, operating factors and all other variables bearing on the superheater performance.

The uniformity of the superheat obtained with Elesco superheaters in three well-known stations is demonstrated by the curves in Fig. 60. The two lower curves are for Elesco superheaters in semi-vertical boilers. The upper curve shows results obtained by a convection type Elesco superheater for high degree superheat.

Safety and Security of Operation

The design and construction of the Elesco superheaters comply in every respect with the A. S. M. E. Code, as well as the laws and regulations of any state in which they are installed. All parts of the superheater under pressure are made of open-hearth steel and have a large factor of safety. Elesco superheaters may be used under maximum pressure conditions incident with present-day power plant practice.

Elesco superheaters can safely be employed up to a steam temperature of 800 deg. Since their temperatures fluctuate very little at various ratings, 800 deg. can be adopted as the

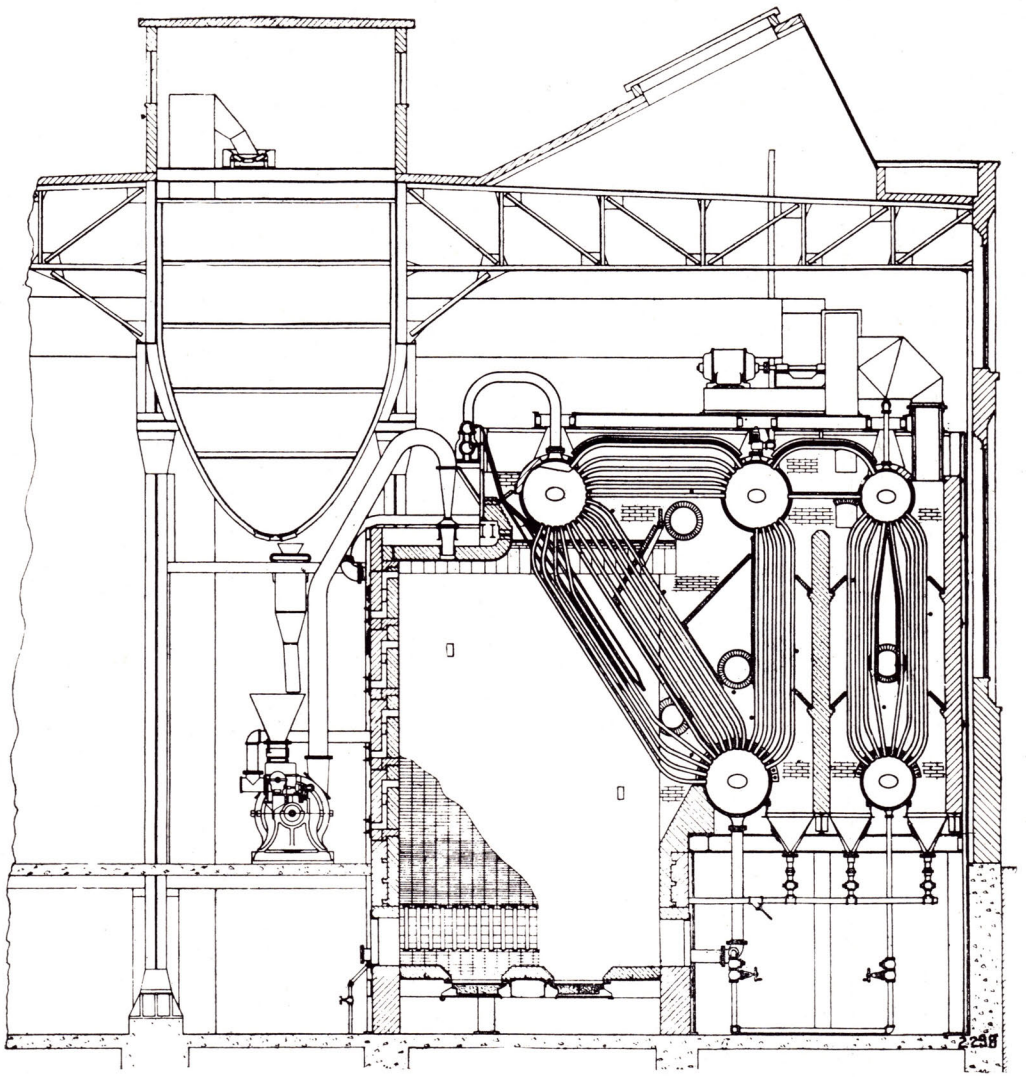

FIG. 61 Elesco Superheater in an Erie City Inclined 3-Drum Water Tube Boiler, with Integral Economizer and Pulverized Fuel Furnace.

operating temperature. This temperature can be used with any pressure up to 800 and 1200 to 1500 lb. per sq. in. For higher pressures, smaller diameter tubes are used and the velocity of the steam is so chosen as to keep the temperature of the material within safe limits.

The diagram in Fig. 62 illustrates the many ways in which the design of Elesco superheaters provides for ample safety and security of operation as discussed below.

Provision for Expansion

Due to the fact that the surfaces of a superheater are exposed to high temperature gases and depend for their cooling upon the flow of steam, internal stresses are occasioned in the superheater structure. This is aggravated by the fact that as steam becomes superheated it absorbs heat less readily. No matter how well a superheater may be designed, its service is always severer and more apt to cause disturbances in operation than in the case of the boiler. This applies to any superheater but more particularly those for modern boilers designed for high pressure and high temperature. All such variations are adequately taken care of by Elesco superheaters, as the units are always free to expand or contract, being fixed at *one end only.*

Joints

The only joints are the metal-to-metal ball joints connecting the units to the headers. This type of joint remains absolutely tight and has proved entirely satisfactory for any working pressure. The clamps and studs are of special

heat-treated steel and so tempered as to withstand any stress or strain to which they are subjected.

Units

Elesco units are made of heavy gage, small diameter, seamless steel tubing. High, uniform steam velocities keep their temperature within safe limits. The units are free to expand and contract under all temperature fluctuations. Pieces of tubing are joined together by means of the forged return bend, described on page 37, eliminating the possibility of failure.

Headers

Both the headers and unit joints are protected from the direct action of the gases. They are either outside the boiler setting or inside in the cool zone of the last pass. In the latter arrangement a baffle of firebrick is placed in front of the headers.

The headers are made of extra strong or thicker open-hearth steel pipe, the wall thickness being dependent upon the pressure. They are round and without handholes opposite the unit openings. In the standard headers for normal pressures, Fig. 88, there is an inside bar reinforcement extending in sections the entire length of the header, uniformly distributing the stresses of the unit studs. In the eccentric headers for the higher pressures, Fig. 89, the unit studs are located in the heaviest side of the header. The inlet and outlet ends are flanged for pipe connections.

The superheated steam header is fitted with a safety valve and thermometer well. Both headers are equipped with drain valves and connections for pressure gages.

Safety Valve

The safety valve furnished with an Elesco superheater is set to open before the main safety valves of the boiler. In case this pressure is exceeded, the superheater safety valve blows, causing a flow of steam through the superheater units, thus protecting the units from overheating.

Unit and Header Supports

The units and headers are supported from the steel work which supports the boiler. The units are spaced by special sectional heat-resisting supports which usually are supported from outside steel work in a manner that permits free

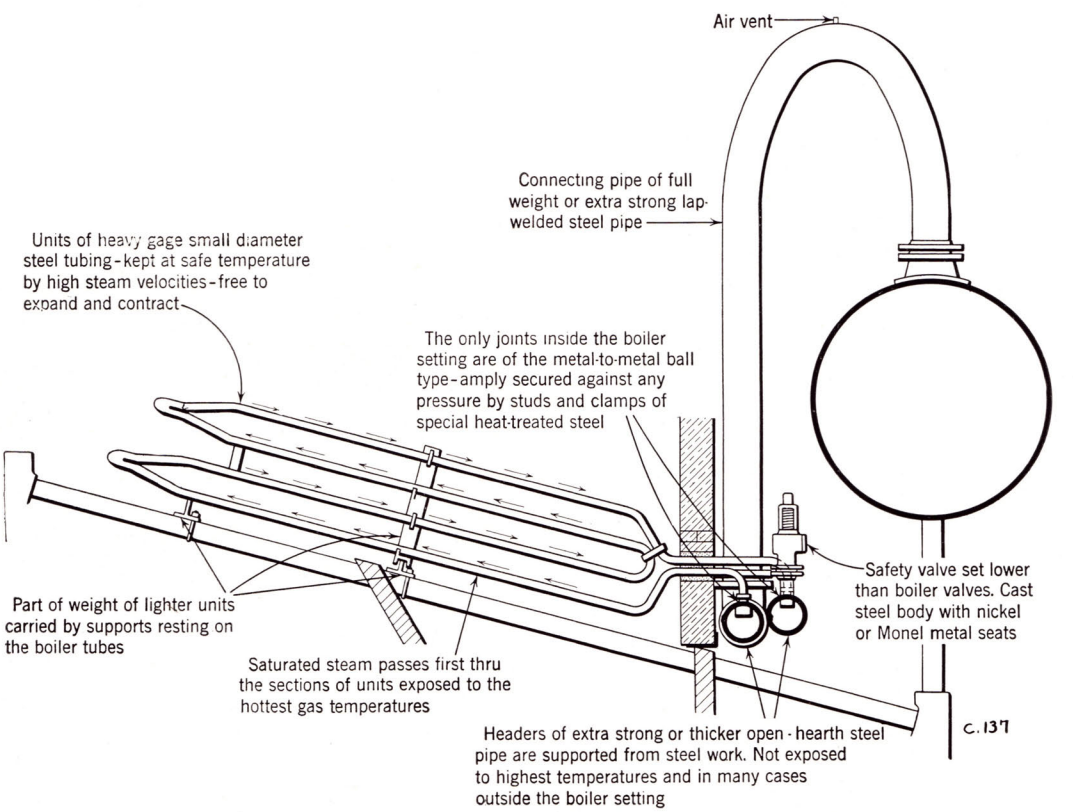
Air vent
Connecting pipe of full weight or extra strong lap-welded steel pipe
Units of heavy gage small diameter steel tubing - kept at safe temperature by high steam velocities - free to expand and contract
The only joints inside the boiler setting are of the metal-to-metal ball type - amply secured against any pressure by studs and clamps of special heat-treated steel
Safety valve set lower than boiler valves. Cast steel body with nickel or Monel metal seats
Part of weight of lighter units carried by supports resting on the boiler tubes
Saturated steam passes first thru the sections of units exposed to the hottest gas temperatures
Headers of extra strong or thicker open-hearth steel pipe are supported from steel work. Not exposed to highest temperatures and in many cases outside the boiler setting
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FIG. 62 Diagram of an Elesco Superheater, Illustrating the Many Ways in Which Elesco Superheaters Provide for Safety and Security of Operation.

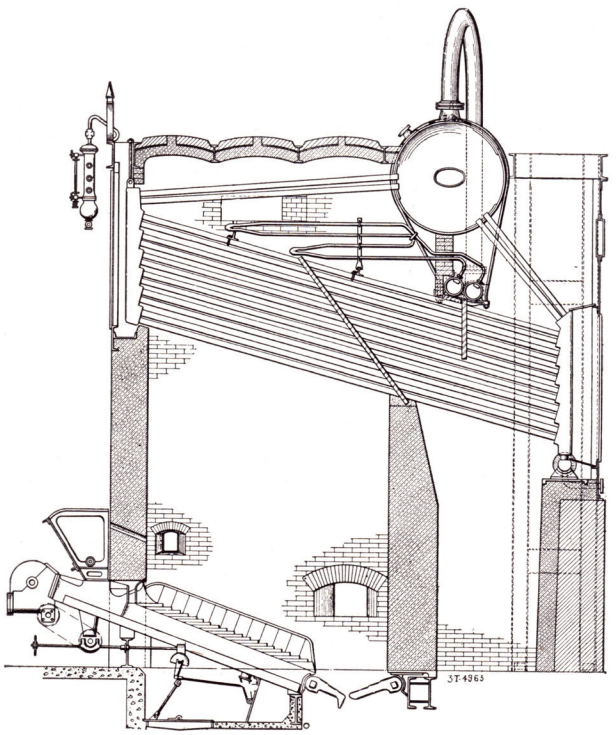

FIG. 63 Convection Type Elesco Superheater in a Springfield Horizontal Cross Drum Boiler. The Superheater Units Are Horizontal but, Being of Small Diameter Tubing, Afford Small Opportunity for Collection of Soot and Ashes.

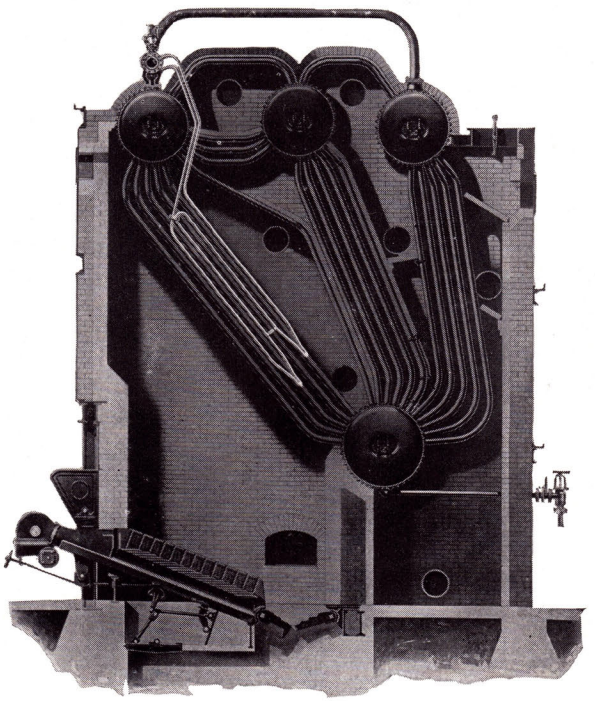

FIG. 64 Elesco Superheater in a Hedges Walsh Weidner (Casey-Hedges Type) Semi-vertical Boiler.

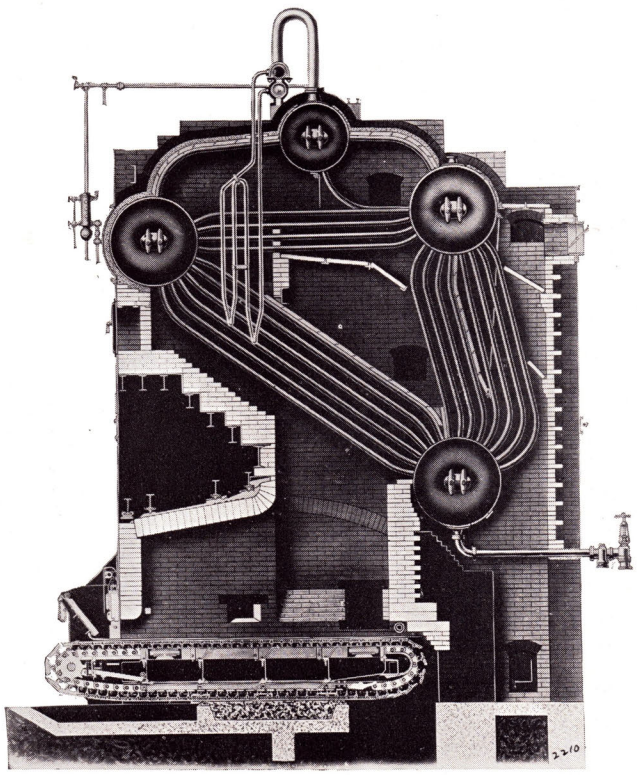

FIG. 65 Elesco Superheater in a Vogt Curved Tube (Class M) Boiler. The Superheater Units Are Vertical and Cannot Collect Soot or Ashes.

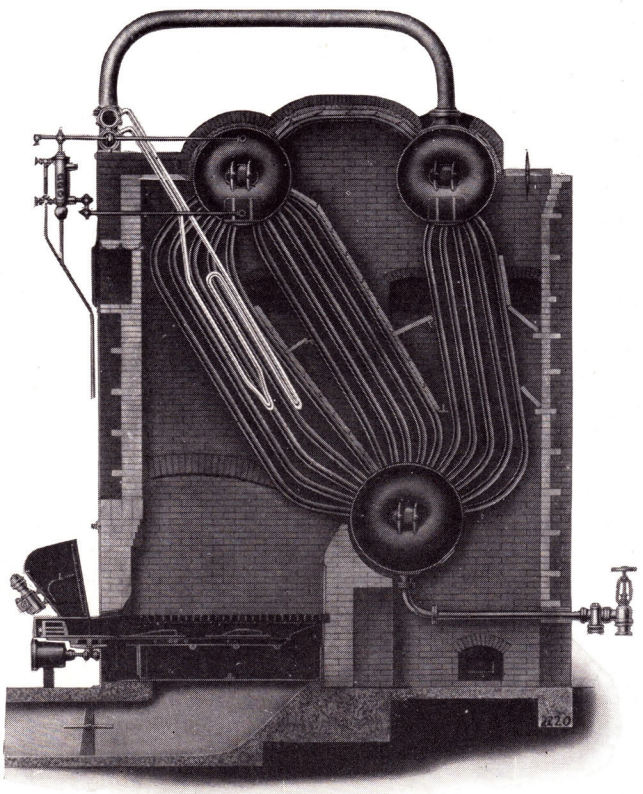

FIG. 66 Elesco Superheater in a Vogt Curved Tube (Class R) Boiler. The Superheater Units Are Inclined and, Being of Small Diameter Tubing, Afford Small Opportunity for Collection of Soot or Ashes.

and independent expansion of boiler tubes or superheater units. In convection type superheaters for horizontal boilers, part of the weight of the units is carried by the supports resting on the boiler tubes.

Connecting Pipe

The connecting pipe is of lapwelded or seamless steel pipe, and Van Stoned with square corners, using forged steel flanges.

Complete Accessibility for Inspection and Maintenance

If accessibility were the only outstanding feature of the Elesco superheater, it would be of sufficient merit to place this superheater in a class by itself. Operating men consider its accessibility one of the most important advantages of the Elesco design. Their experience has shown that a successful superheater, to meet present-day power plant operating conditions, must have ready accessibility without tearing down large portions of the boiler. Neither must it require the services of skilled mechanics and boilermakers to maintain.

In Elesco superheaters wherever the headers and unit joints are located outside the boiler setting, as in semi-vertical boilers (Fig. 70), all the parts which may be subject to leakage of steam are within convenient reach for inspection, correction or replacement. When located within the setting, they are readily accessible through access doors in the side wall or roof. See Fig. 63.

When the unit joints and headers are located outside the setting, any or all of the units may be removed and replaced easily and quickly by the usual power-house mechanics and without entering the boiler setting, thereby avoiding the necessity of entirely cooling off the boiler.

Each unit joint is of the metal-to-metal ball type and can be broken merely by removing the nut that holds the unit clamp in place. The ease with which Elesco superheater units may be disconnected from the header is demonstrated in Fig. 67. An important additional advantage of the ball joint is that no other opening is necessary in the header for applying or disconnecting a unit; no material or parts are destroyed or damaged in disconnecting a unit from its header. Contrast this with the rolled joint which requires a handhole opposite each connection for application, and in disconnecting necessitates actual destruction of the unit at the joint.

These are some of the reasons why power plant engineers who have had experience with the ball joint (fully described on page 35) are convinced that from an operating and maintenance standpoint it is superior to all other forms.

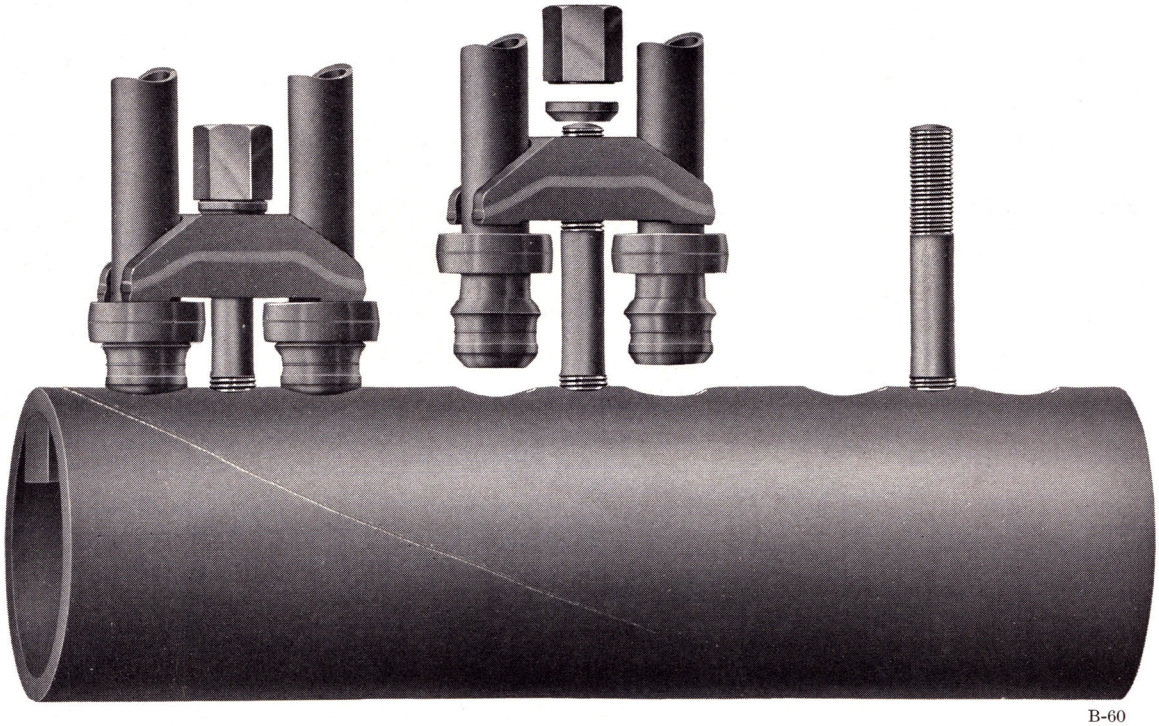

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FIG. 67 Elesco Superheater Units Are Attached to the Header by Metal-to-Metal Ball Joints, and Can Be Disconnected Merely by Removing Unit Nut.

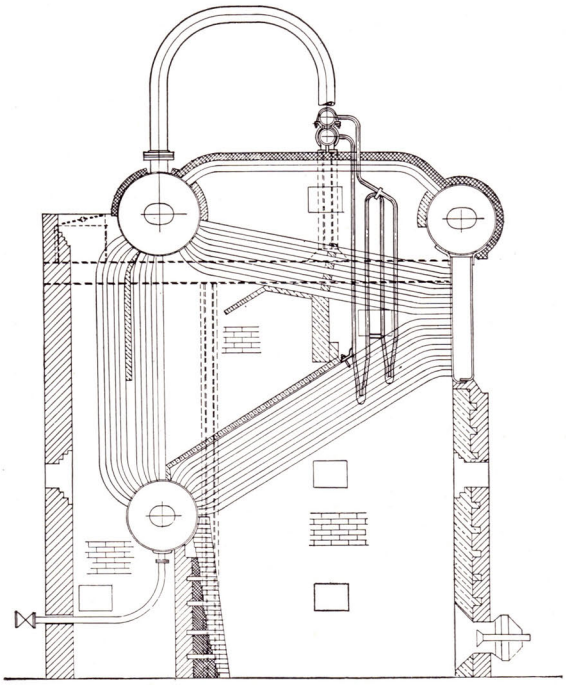

FIG. 68 Elesco Superheater in a Collins Water Tube (Semi-vertical) Boiler.

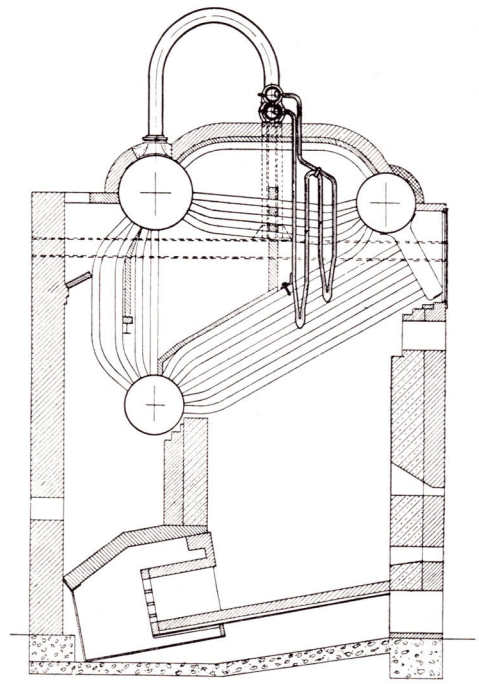

FIG. 69 Elesco Superheater in a Collins A-type or Oil Field (Semi-vertical) Boiler.

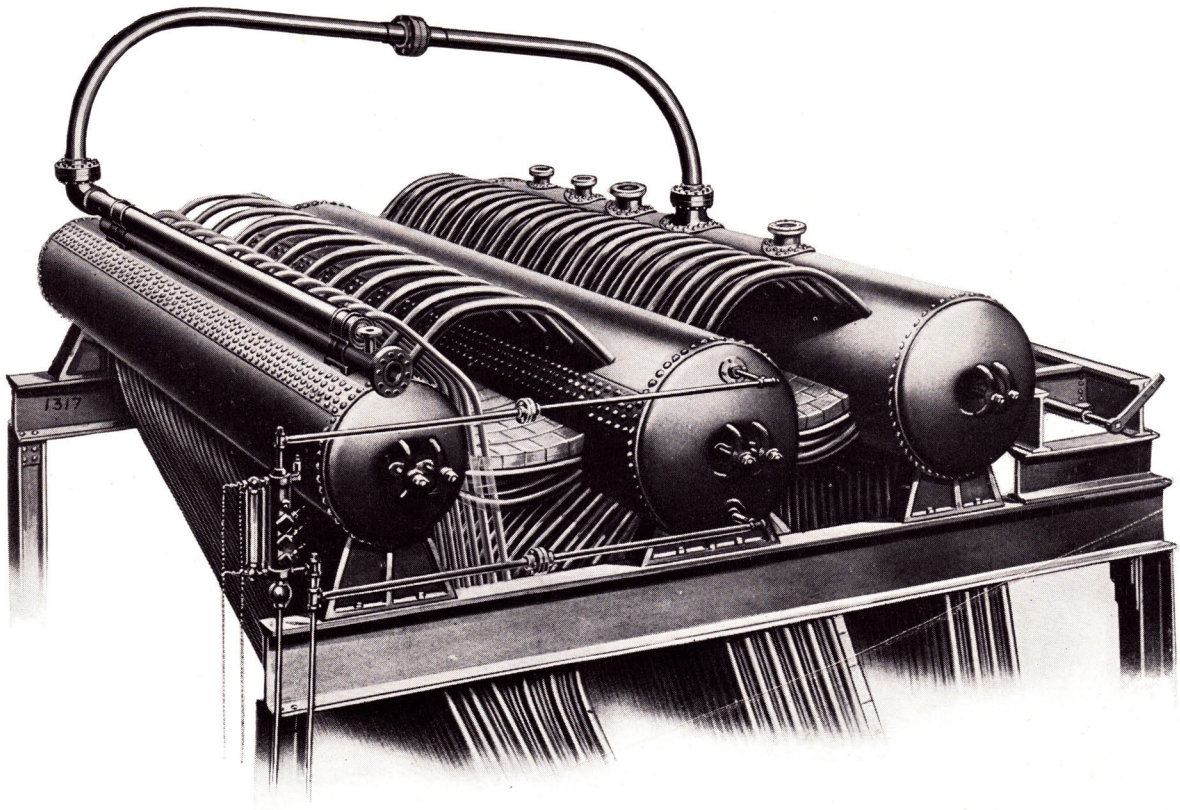

FIG. 70 Top View of Heine V-type Boiler with Elesco Superheater (Fig. 71), Showing Arrangement of Headers and Unit Joints. In All Elesco Superheaters for Semi-vertical Boilers the Headers and Unit Joints Are Located on Top of the Boiler and Outside of the Setting as Here Shown.

Freedom from Soot Deposits

Because the reduction in heat transfer due to deposits of soot and ashes is proportionately much greater with superheater units than with boiler tubes, maintaining the superheater units free of soot and ashes is correspondingly of greater importance. Being made of smooth seamless steel tubing, Elesco units afford small opportunity for the collection of soot, even where the units are arranged horizontally. When the type of boiler permits, the units are inclined or vertical, so it is practically impossible for soot or ashes to adhere to the unit surfaces. Three arrangements of Elesco superheater units are shown in Figs. 63, 65 and 66.

In certain classes of waste heat boilers with gases carrying large amounts of dust, the bare tube feature of Elesco is vitally important in offering minimum opportunity for deposits.

Another factor which tends to give the least opportunity for adhesion of dust and soot is even distribution of gases over all the superheating surface. There are no dead gas areas or pockets through Elesco superheaters.

Minimum Draft Loss

The present-day demand for higher boiler capacities calls for heavy drafts. While Elesco superheaters are so arranged and located as to give uniform and high heat absorption, they also give the least possible resistance to the flow of gases for any given superheating capacity. There are several reasons: The units are of small diameter smooth tubing, which enables the designer to place large heating surface in a limited space. The units may be made in any shape necessary to fit into the available space. Oftentimes the units are placed in one of the banks of boiler tubes. The units are, as noted on page 22, staggered, which lessens the tendency to restrict draft, while further assuring even distribution of the gases.

In no arrangement of Elesco superheaters is the draft loss of such a magnitude that it can be measured with ordinary draft indications, except at extremely high boiler ratings. At such ratings the draft loss is a very minute quantity as compared with the draft loss through the boiler proper. The curves in Figs. 76 and 77 are typical results from Elesco superheaters.

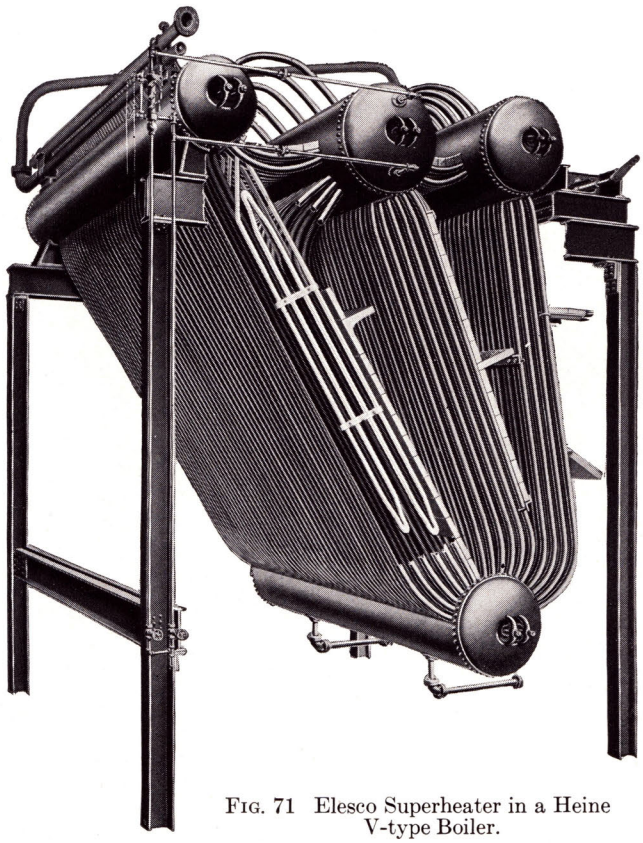

FIG. 71 Elesco Superheater in a Heine V-type Boiler.

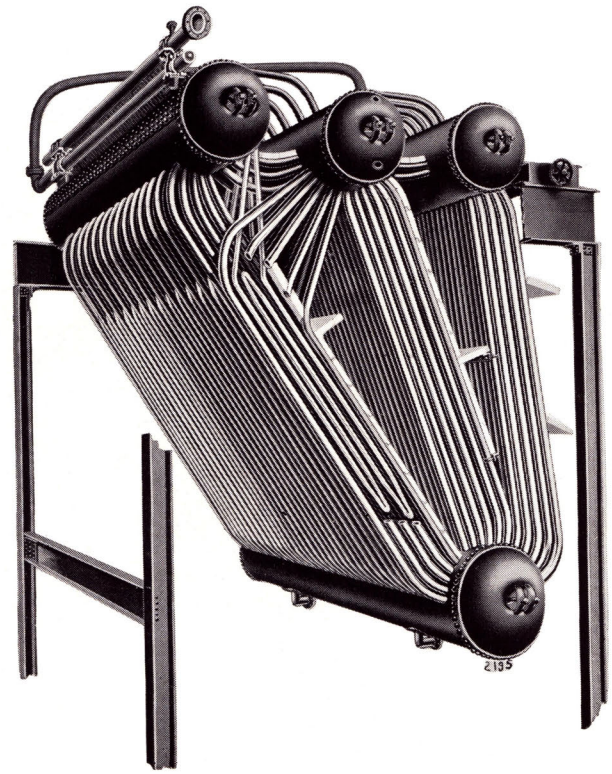

FIG. 72 Elesco Superheater in a Hedges Walsh Weidner (Walsh and Weidner Type) 4-Drum Bent Tube Boiler.

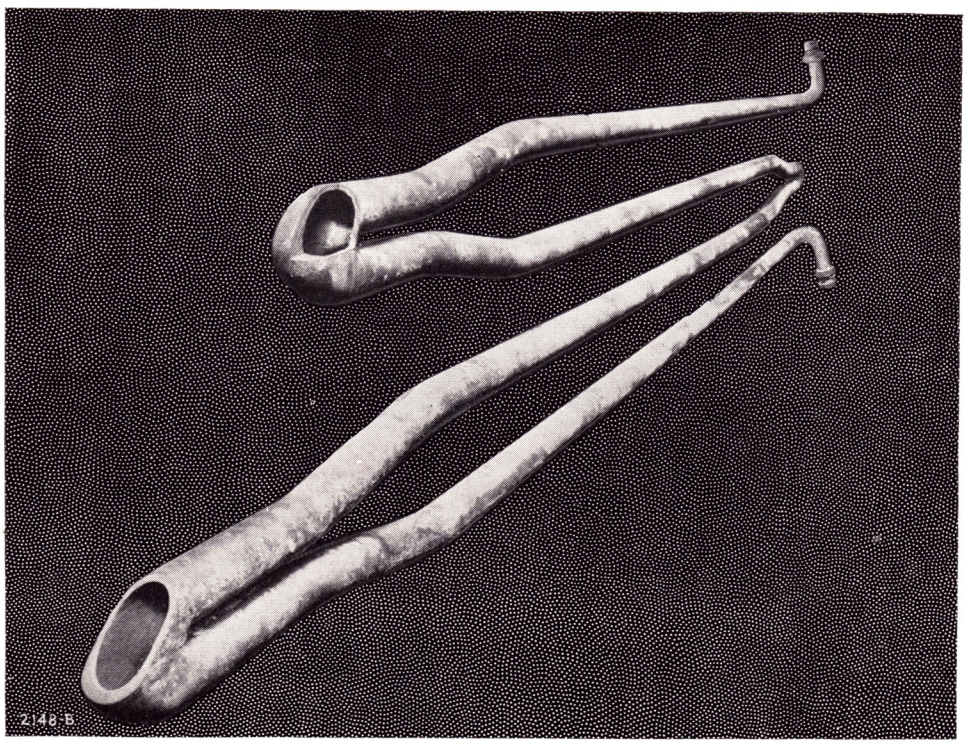

FIG. 73 A Two-loop Elesco Superheater Unit Taken from an Interdeck Type Superheater in One of the 1890-hp. Boilers at the Hell Gate Station, United Electric Light and Power Company, New York, After 6 Years' Service. This Unit Is Made Up of 48 Feet of 1¾-In. Tubing and Has 17 Sq. Ft. of Steam-touched Heating Surface. Note at Cuts in Return Bends That the Internal Surfaces Are Clean.

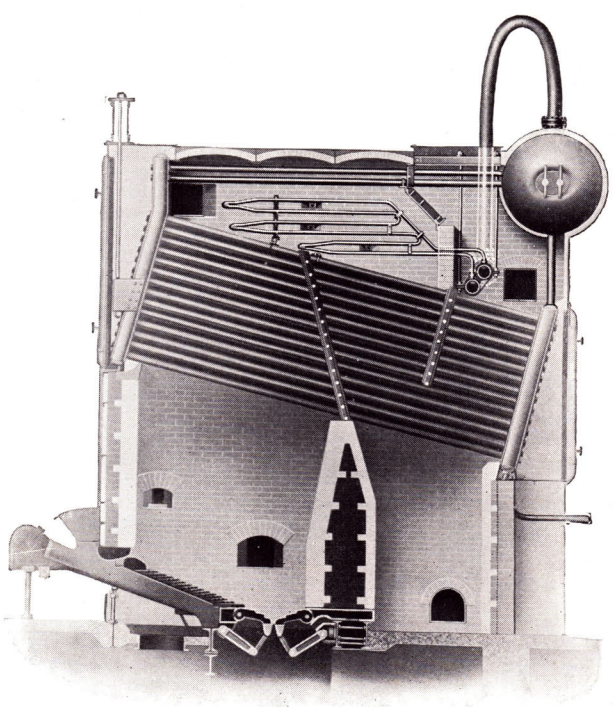

FIG. 74 Convection Type Elesco Superheater in a Hedges Walsh Weidner (Walsh and Weidner Type) Horizontal Cross Drum (Box Header) Boiler.

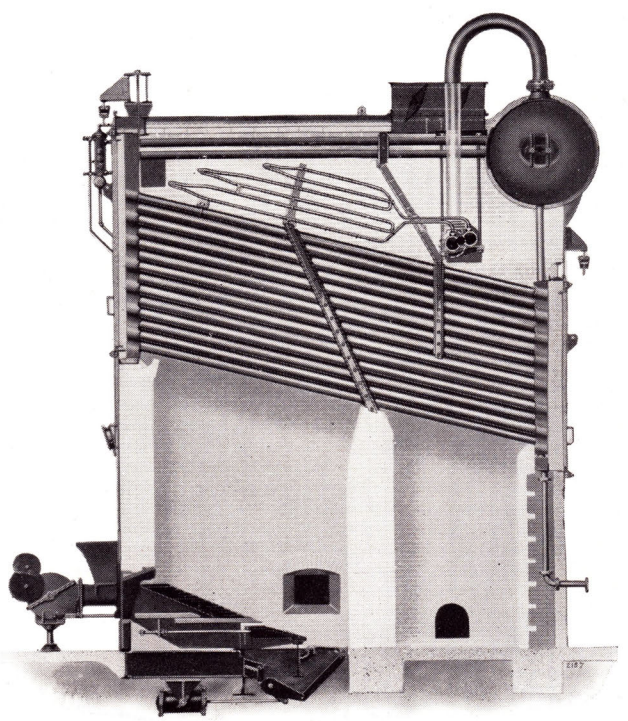

FIG. 75 Convection Type Elesco Superheater in a Hedges Walsh Weidner (Walsh and Weidner Type) Forged Steel Sectional Vertical Header Horizontal Cross Drum Boiler.

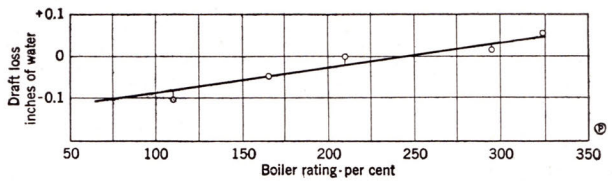

FIG. 76 Draft Loss Through an Elesco Superheater in a 1500-hp. Heine V-type Boiler (Fig. 59), Moores Park Station of the City of Lansing, Mich.

Long Life

Elesco superheaters are constructed of materials which many years of experience have proved satisfactory. The design also is such as to reduce the stress to which the parts are subjected in operation. Superheater headers and unit joints, being located either outside the boiler setting or inside in a low temperature zone, are completely protected from the action of the extremely hot gases. There are no steam joints in the path of the hottest gases. High velocity through the units protects them against overheating. As no flooding devices are used, there is no opportunity for scale to accumulate in the units on this account, and interfere with the heat transfer.

The units in Figs. 73 and 79, taken from two prominent stations, show the excellent condition of Elesco superheater units after several years service under severe operating conditions.

When boiler water conditions are such that periodic turbining of the boiler tubes is required, all the boiler auxiliaries, including the superheater, usually are inspected also. The fact that Elesco superheater units are readily removable for such inspection and cleaning, and easily replaced, adds greatly to the life of the superheater.

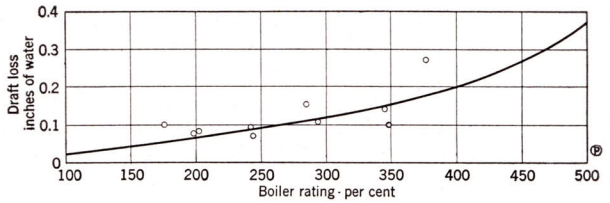

FIG. 77 Draft Loss Through an Elesco Superheater in a 1500-hp. Bigelow-Hornsby Semi-vertical Boiler, Toledo Edison Company, Toledo, Ohio.

High Steam Velocities

In passing through an Elesco superheater the steam is broken up into many small streams; hence it passes through the units at high velocities. The units are proportioned to obtain the desired superheat with a high steam velocity, and without an excessive drop in pressure, by the selection of the proper size of small diameter tubing. Longer units are made possible by the forged return bend, a description of which appears on page 37.

High steam velocities in Elesco superheaters keep the inside of the units clean, prevent accumulation of any foreign matter which may come over in the steam and which becomes more objectionable with higher steam pressures and temperatures. The metal temperature of a superheater unit in contact with the hot gases is established somewhere between the temperatures of the gas and the steam. The higher the velocity of the steam and the cleaner the inside of the tubes, the nearer the temperature of the metal is to that of the steam and the higher the rate of heat transfer.

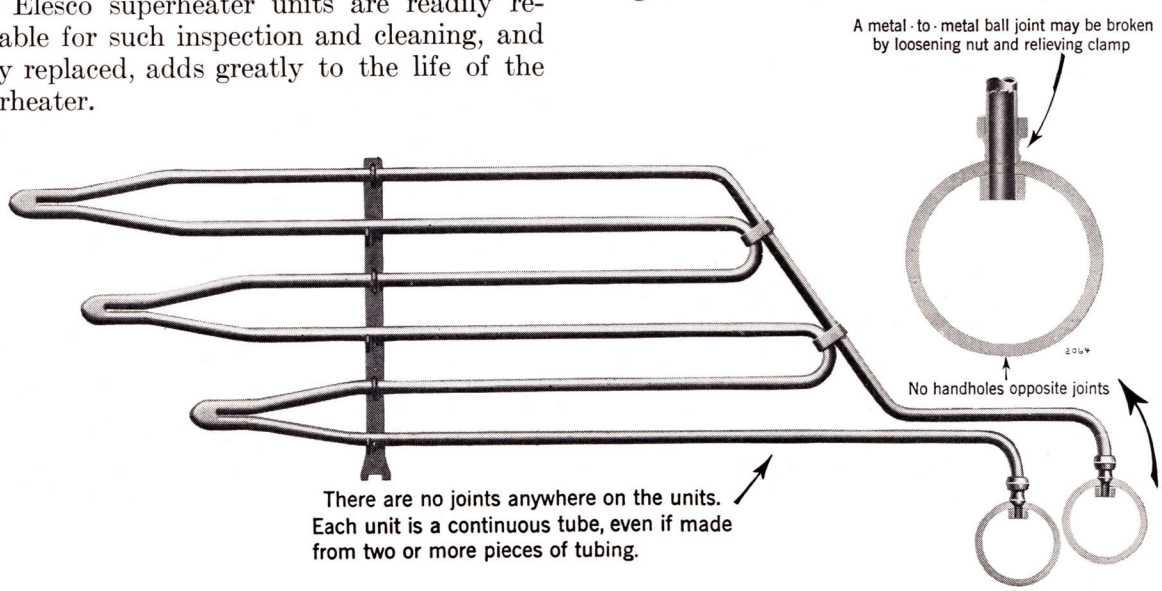
A metal - to - metal ball joint may be broken by loosening nut and relieving clamp
No handholes opposite joints
There are no joints anywhere on the units. Each unit is a continuous tube, even if made from two or more pieces of tubing.

FIG. 78 Detail of Elesco Superheater Unit and Headers.

Minimum Possibility for Leaks

The only joints in Elesco superheaters are the ball joints connecting the units to the headers, as diagrammatically illustrated in Fig. 78. In other designs of superheaters having the same amount of heating surface, there may be from two to three times as many joints to be kept steamtight. The ball joint construction provides a tight joint for any pressure and temperature conditions as demonstrated by its performance under the severest conditions.

Flexibility and Adaptability to Any Design of Boiler

Elesco superheaters are not fixed as to position in relation to the boiler proper and may be so located as to best produce the desired results, taking full advantage of the variation of gas temperatures in different locations. Compare the location of the Elesco superheater in the many illustrations throughout this bulletin.

This flexibility of the Elesco design makes possible utilization of portions of the gas paths in the usual types of boilers, which but for this flexibility would not be available. Also in many cases the units may be placed closer to the furnace without exposing them to overheating. By the proper proportioning of the surfaces and areas, all the advantages of the Elesco superheater are possible for any combination of operating conditions.

First Cost Consistent with Results

Equipment theoretically correct and of proved economy under average conditions is not necessarily always so under all conditions. Where its application necessitates revamping apparatus already installed, this cost may at times outweigh the possible advantages.

While the Elesco superheater is a thoroughly practical device, it is recommended only after Elesco engineers have ascertained that its installation will prove a profitable investment. This gives assurance that the installed apparatus actually is economic.

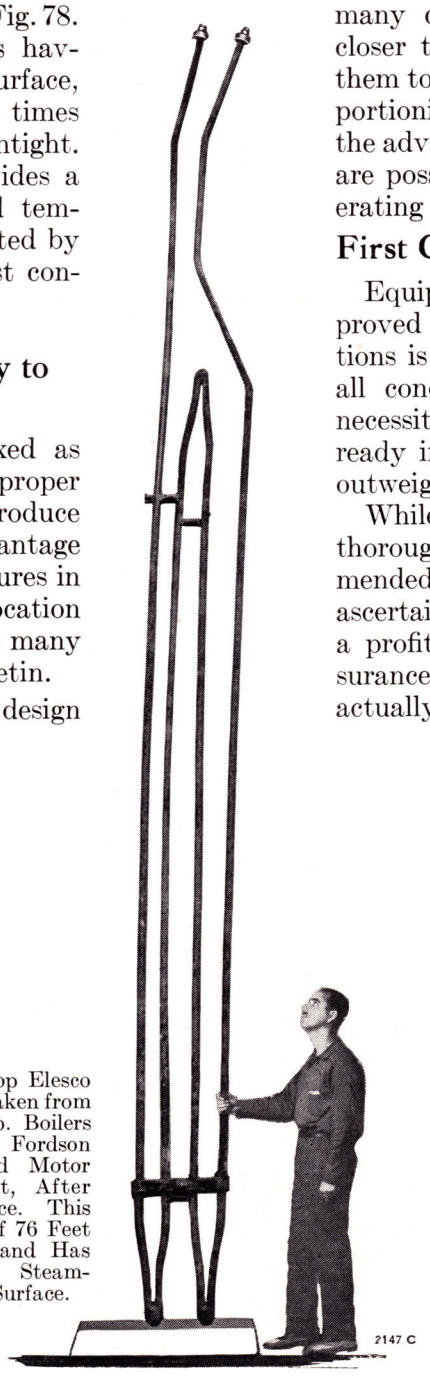

FIG. 79 A Two-loop Elesco Superheater Unit Taken from One of the 2647-hp. Boilers (Fig. 27) at the Fordson Power Plant, Ford Motor Company, Detroit, After Seven Years' Service. This Unit Is Made Up of 76 Feet of 1½-in. Tubing and Has 20.8 Sq. Ft. of Steam-touched Heating Surface.

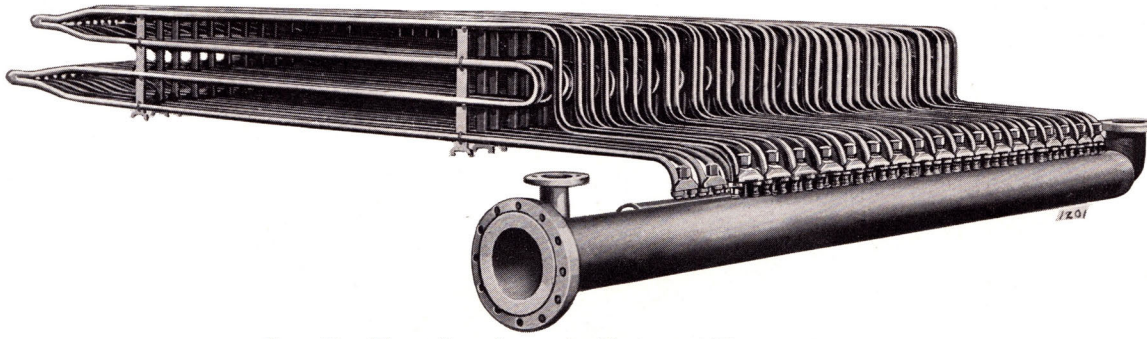

FIG. 80 Elesco Superheater for Horizontal Water Tube Boiler.

Design Details of the Elesco Superheater

Inherent features of the Elesco design of steam superheaters are the ball joints and forged return bends, illustrated in Figs. 82 and 85. These features, which give extraordinary flexibility to the Elesco design, make it possible to utilize portions of the gas paths in the usual types of boilers that otherwise would not be available. It is also possible in many cases to place the superheater units closer to the furnace without exposing them to overheating. By the proper proportioning of the surfaces and areas, all the advantages of the Elesco superheater are realized for any combination of operating conditions.

Ball Joints

Elesco superheater units are attached to the distributing and collecting headers of the superheater by means of clamped metal-to-metal ball joints; neither threaded, rolled nor autogeneously welded joints are used. Fig. 85 illustrates this joint in section. It shows how the unit ends fit into ground 45-deg. conical seats in the headers. Fig. 84 also shows how the unit ends are held in place by drop-forged clamps and heat-treated steel studs. This joint eliminates the necessity of handholes in the headers, and thus reduces the number of joints. In other designs of superheaters having the same heating surface, handholes in the headers may necessitate two to three times as many joints to be kept steamtight. The ball joint originally was designed for high pressure work and is used also for conditions subject to severe vibration. It permits of quick and easy application or removal of units without special tools. It is flexible, remains tight under the severest operating conditions, and is easy to adjust and maintain.

The ball-shaped ends on the superheater units are formed in steps as shown in Fig. 81. The ends of the units are first subjected to a special upsetting or forging process. After this operation the ends are faced in a lathe and ground to form true parts of a sphere so that they will fit into the 45-deg. conical seats in the header. These seats are so ground that each ball end will have a line contact at the center of the 45-deg. face.

FIG. 81 The Ball Ends of Elesco Units, Illustrating the Steps Necessary for Upsetting Ends of Units and Facing and Grinding Ends to a Ball Shape.

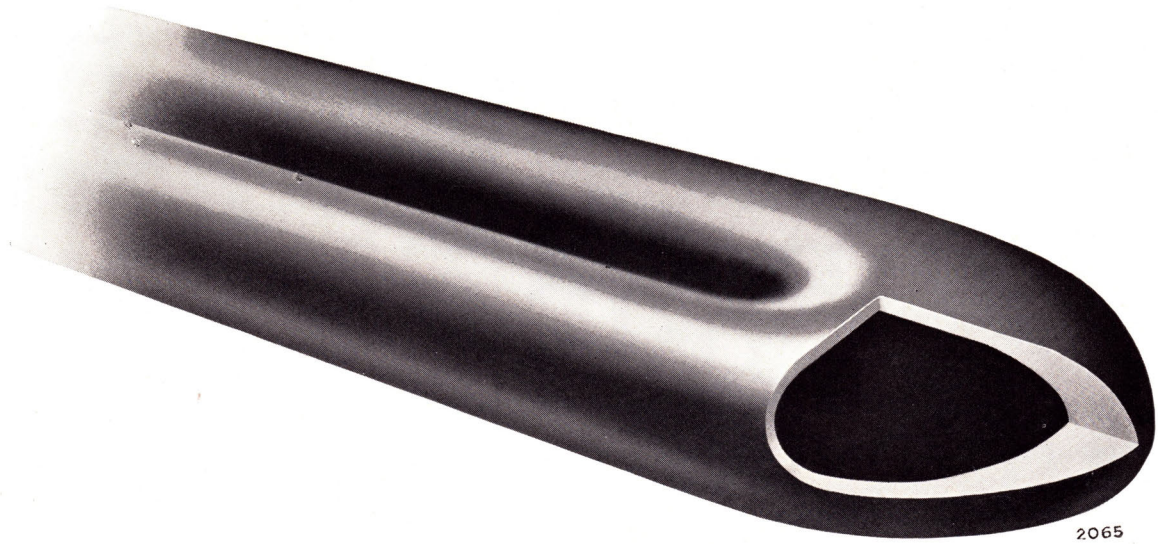

FIG. 82 The Elesco Forged Return Bend.
Unrestricted Steam Area—Machine Forged—An Integral Part of the Superheater Tubing—
Stronger Than the Tubing Itself.

FIG. 83 Steps Necessary for Making Elesco Forged Return Bends to Join Pieces of Tubing in Fabricating Elesco Superheater Units.

Both clamps and washers for the ball joints are made of steel. The clamp studs are made of special heat-treated alloy steel having a minimum tensile strength of 100,000 lb. per sq. in. Assembled ball joints and header are shown in Fig. 84. They are also shown in section in Figs. 88 and 89.

Forged Return Bends

By means of Elesco forged return bends it is possible to make multiple loop superheater units of any length, despite limitations in length of tubing obtainable from the mill, and without locating joints of any kind in the path of extremely hot gases. With the multiple loop arrangement, exclusive in Elesco superheaters, it is possible to obtain the desired superheat with a single-pass superheater comprising many units, all of the same length, except under exceptionally rare circumstances. Since different sizes of tubing can be used in the manufacture of Elesco units, these features give the superheater designer full control over the proportions of heating surface and steam area of the superheater—a very important matter in design.

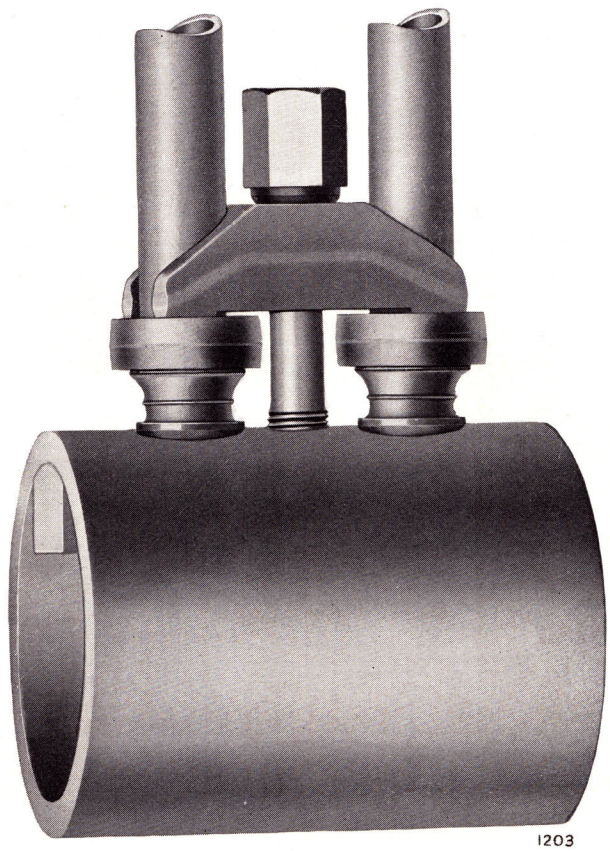

FIG. 84 Section of Elesco Superheater Header Showing How Units Are Clamped to the Header.

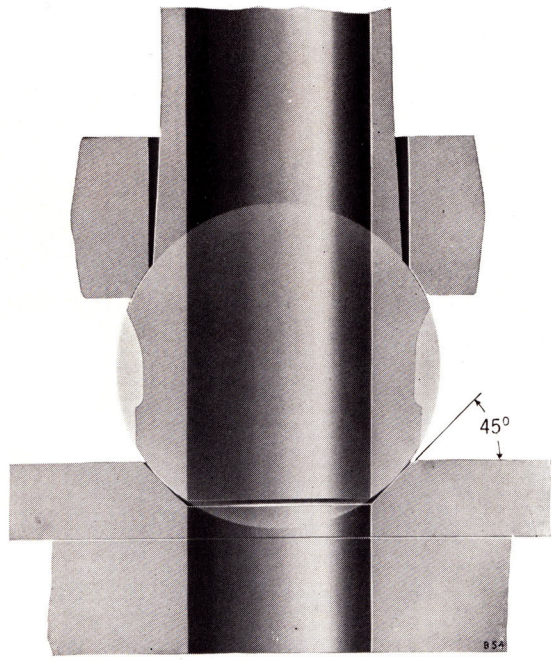

FIG. 85 Elesco Ball Joint in Section. The Unit Ball Ends Are True Parts of a Sphere and Make a Line Contact at Center of 45-deg. Seat in Header.

The sharp reversal of steam flow at the return bends breaks up the wet center core of steam, effectively prevents water from being carried through the superheater and avoids stratification of the steam flow, where any of these conditions exists, thus increasing the heat transfer and causing all particles of the steam to be superheated uniformly. There is no restriction of steam area at the bends, nor undue restriction of the gas flow area.

Elesco forged return bends are made in steps, as shown by Fig. 83, accompanied by the proper heating in each case. This is a mechanical die-forging process without the use of either additional material or a flux and constitutes a true forged bond performed under ideal conditions. Two pieces of seamless steel tubing of practically any available length that are to be made into a return bend are clamped together, heated to the proper degree and placed in the forging machine. By means of a die and pin operation the inner sides of the two pieces are cut and forged together to form what is called a breeches piece. This is then heated and machine-hammered to a form shown in the third step.

After the preliminary swaging the partially closed bend is heated and placed in a swage,

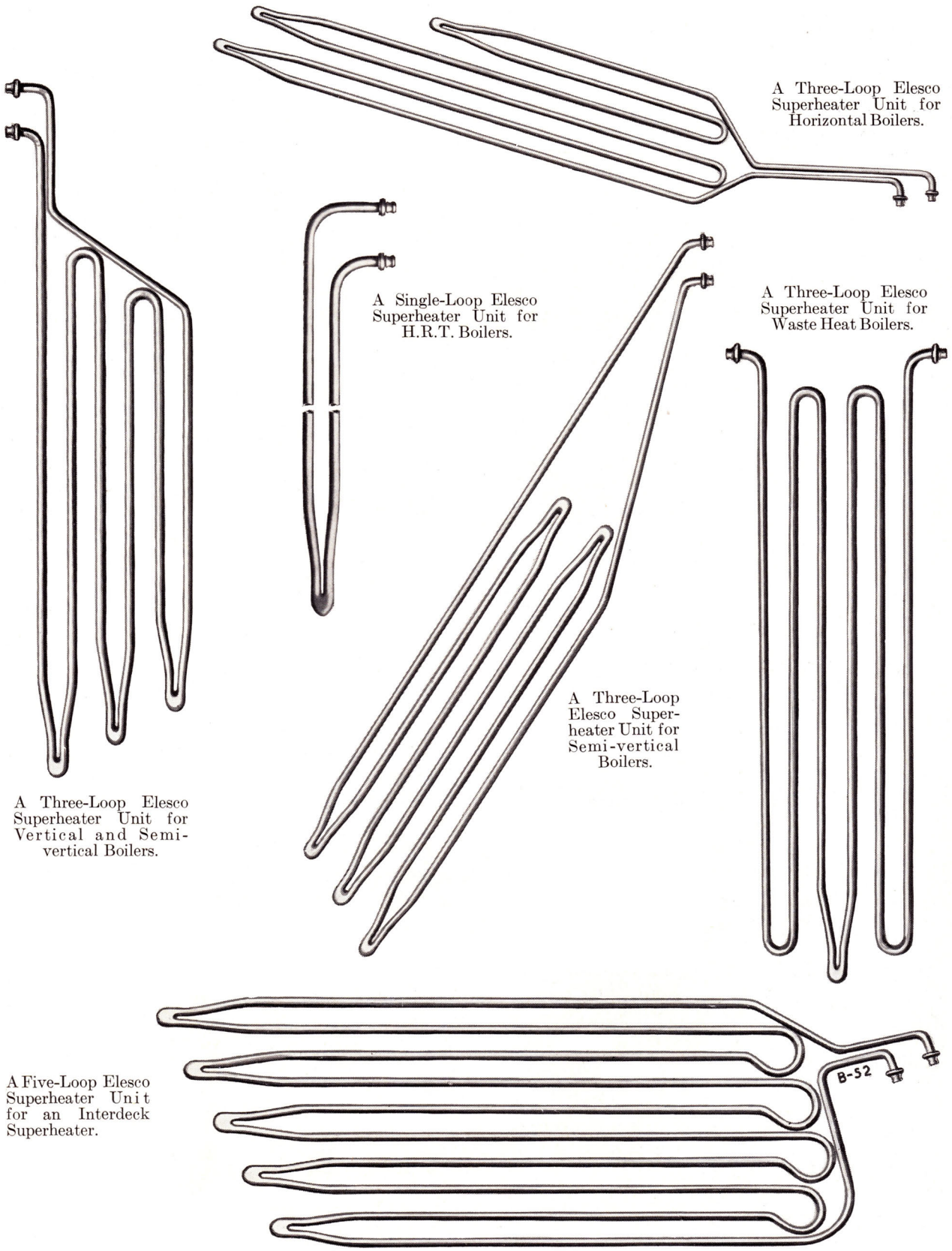
A Three-Loop Elesco Superheater Unit for Horizontal Boilers.
A Single-Loop Elesco Superheater Unit for H.R.T. Boilers.
A Three-Loop Elesco Superheater Unit for Waste Heat Boilers.
A Three-Loop Elesco Superheater Unit for Semi-vertical Boilers.
A Three-Loop Elesco Superheater Unit for Vertical and Semi-vertical Boilers.
A Five-Loop Elesco Superheater Unit for an Interdeck Superheater.
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FIG. 86 Typical Elesco Superheater Units, Illustrating the Elesco Principles of Design Applied to Different Style Units

where the opening is closed by a series of hammer blows to a shape about as shown in the fourth step. The remainder of the process consists of flattening the bend, cutting off the short tip and rounding the end, with the proper amount of heating involved in each case.

Units so formed are homogeneous and as strong as the tubing of which they are made. In addition, the thickness of the metal is increased at the bend so that it is stronger than the straight tubing. Millions of these return bends are in daily use under the severest conditions.

Superheater Units

Upon leaving the saturated steam header, the steam passes through a number of superheater units arranged as multiple loops in parallel. These units are of such shape as to cause the steam to travel several times back and forth through the hot gas zone, thus insuring uniformity of superheat. Typical Elesco superheater units are shown in Fig. 86.

Elesco units are made of heavy gage, small diameter, seamless steel tubing, and have smooth inside and outside surfaces. There is no external roughness to catch soot. The inside cross-sectional area is uniform throughout, and is proportioned to give efficient velocity without resorting to cores. The form of the units is such as to permit free expansion and contraction of all parts.

Theoretically, the smaller the tube and the higher the velocity, the greater the rate of heat transfer. Practice has demonstrated that small diameter, seamless steel tubing, with the Elesco forged return bend, generally gives the most satisfactory results in the stationary field as to heat transfer, pressure drop and physical construction. The excellent rate of heat transfer attained in Elesco units is largely due to these featuers of design.

Headers

The headers and unit joints are protected from the direct action of the gases. They are either outside the boiler setting or inside the boiler in the cool zone of the last pass. In the latter arrangement a baffle of firebrick is placed in front of the headers. The unit joints in the headers are so arranged that they are accessible for inspection or repair.

The headers are suspended from steel supports, independently of the brickwork, and are free to expand and contract in all directions.

Standard headers for normal pressures are made of extra strong or thicker open-hearth steel pipe, the wall thickness being dependent upon the pressure. They are round and without handholes. In this type header, as shown in Fig. 88, there is an inside bar reinforcement extending in sections the entire length of the header uniformly distributing the stresses of the superheater unit studs.

In Fig. 89 is shown an eccentric header designed for the higher pressures. This type of header is a rugged construction quite capable of withstanding the highest pressures in use today (800 to 1500 lb. per sq. in.). The unit studs are located in the heaviest side of the header, thereby obtaining a uniform stress throughout the cross-section. It will be seen that the metal-to-metal ball joints connecting the units to the header and the method of clamping units are the same arrangement as applied to the standard header.

The saturated steam inlet and the superheated steam outlet are always located at opposite sides of the setting. This arrangement insures uniform distribution of steam through the units at all boiler loads. The inlet and outlet ends are flanged for pipe connections. The superheated steam header is fitted with a safety valve and thermometer well. Both headers are equipped with drain valves and connections for pressure gages.

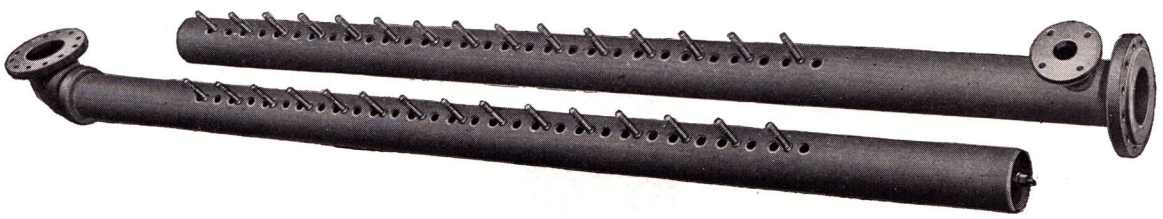


FIG. 87 General Header Arrangement.

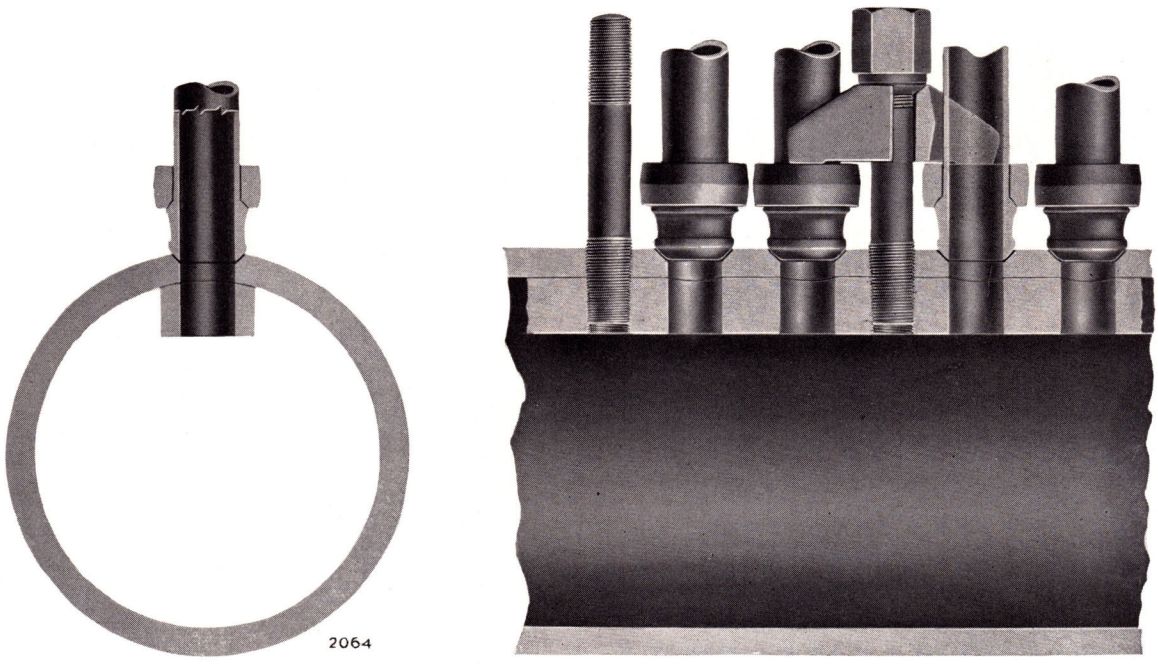


FIG. 88 Elesco Standard Superheater Header and Ball Joints in Section, Showing How the Unit Ball Ends Fit Into Ground 45-deg. Conical Seats in the Header and Are Held in Place by Drop-forged Clamps and Heat-treated Steel Studs. Unit Ball Ends Are Forged Integrally with the Tubing, as Are the Forged Return Bends. The Type of Header Here Shown Is Applied to Superheaters for Normal Pressures.

The safety valve furnished with an Elesco superheater is provided with outside spring and with nickel or Monel metal seats and discs. It is set to open before the main safety valves of the boiler to protect the superheater units from overheating.

Unit and Header Supports

In the usual convection type superheaters for horizontal boilers, the headers are supported from the steel work which carries the boiler and brick settings. Part of the weight of the lighter superheater units is carried by the headers, the balance being supported by special sectional heat-resisting supports resting on the boiler tubes. The units are prevented from touching the water tubes in a manner that permits free and independent expansion of boiler tubes and superheater units.

In other arrangements, both the units and headers are supported from the steel work which supports the boiler. The units are spaced by the supports which usually are suspended from overhead steel work, permitting free and independent expansion of both boiler tubes and superheater units.

Accessibility

In horizontal boilers the roof construction usually permits ready accessibility of the superheater units through the roof. Where this is not practicable, suitable access doors are placed in the side wall above the units.

To prevent the admission of air past the units where they enter the setting in vertical and semi-vertical boilers, cast-iron plates are provided, grooved to fit snugly around the units. After the seal plates are applied, the small openings around the units are packed with asbestos rope. Fire or common brick is laid as usual on top of the plates for insulation.

In the interdeck design, the units enter the first pass through the first baffle or through cast-iron finger plates. The spaces between the units as they pass through the baffle are filled with firebrick and asbestos mortar. This arrangement is simple and practical and can easily be maintained tight.

Connecting Pipe

The connecting pipe is designed to insure dry steam from the boiler and is so proportioned as to cause the minimum pressure drop between

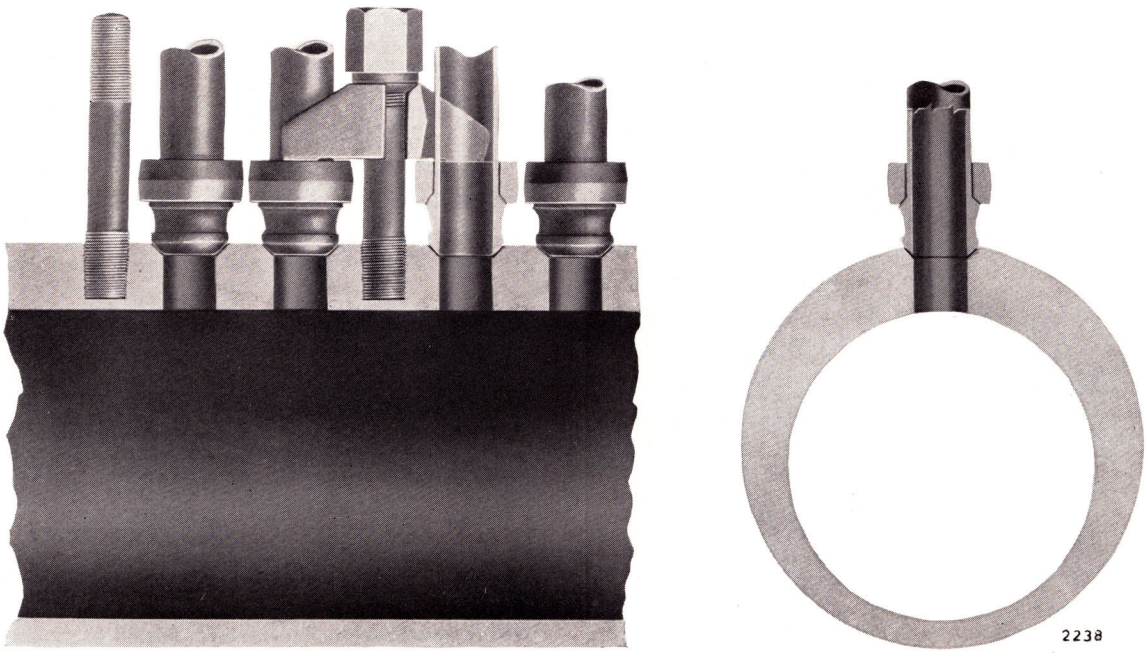


FIG. 89 Elesco Eccentric Superheater Header and Ball Joints in Section. This Type of Header Is Used with Superheaters for High Pressures. The Ball Joints and Clamping Methods Are the Same as for the Standard Construction Shown in Fig. 88.

the boiler and the superheater headers. It is of lapwelded or seamless steel pipe and Van Stoned with square corners, using forged steel flanges.

Summarized Constructional Advantages

1. Superheater located in the most favorable zone for degree of superheat wanted and for uniformity of superheat.

2. Fewer joints to be kept steamtight.

3. Type of joint proved most efficient for high pressures and temperatures.

4. In superheaters for vertical and semi-vertical boilers, H.R.T. boilers, and in many interdeck type superheaters, radiant superheaters and superheaters for waste heat boilers, all joints and headers are located outside of the boiler setting. In other superheater arrangements all joints and headers are located in the coolest gas zone of the boiler.

5. Uniform distribution of steam at all loads.

6. Highest heat transfer rate without objectionable cores.

7. Soot troubles and draft losses reduced to a minimum.

8. Very little weight or no weight at all on boiler tubes, depending on superheater arrangement.

9. Easy to install and inspect.

10. In many types of boilers the superheater can be installed either by opening a small section in roof or through a door in the side wall without disturbing boiler setting.

11. Designed by superheater experts to meet specific requirements.

12. Elesco, the standard of quality, is made by the world's largest manufacturers of superheaters.

Appendix*

Physical Properties of Saturated and Superheated Steam

Completely fill a transparent vessel with water, insert a thermometer and seal the vessel except for a safety valve, set at 5-lb. gage pressure. If then heat is applied to the vessel, the following results will be obtained:

First: The thermometer will show a gradual rise in temperature of the water until it reaches 228 deg. F.

During this period the water will expand and the surplus will be ejected through the safety valve.

Second: When the thermometer shows a uniform temperature of 228 deg. F., boiling will commence and steam will rise to the top of the vessel, forcing more water and then surplus steam through the safety valve, since the steam has a greater volume than the water.

This steam is invisible in the vessel but the instant it is ejected to the cooler atmosphere it condenses and is visible as a mist. At any point between the beginning of boiling and complete evaporation, the steam is known as saturated steam. In the vessel it is saturated steam, at 228 deg. F., the temperature for saturated steam at 5-lb. gage, or 20-lb. absolute pressure (using 15 lb. as atmospheric pressure). Each pressure has its corresponding temperature, which saturated steam attains. In other words, as long as there still is water in the vessel, the steam is saturated and has a definite temperature and a definite volume per pound, corresponding to the prevailing pressure.

When the water is all evaporated, for an instant, the vessel will be full of dry saturated steam.

Third: Now the thermometer will show another rise in temperature. The steam in the vessel will expand and the surplus will be ejected as the pressure remains constant. The steam is now superheated. The ejected portion that has not cooled to 212 deg. F. is invisible because it cannot condense until it has cooled to 212 deg. F. (the saturation temperature corresponding to atmospheric pressure or 15 lb., absolute).

Steam separated from the water from which it was generated may have any temperature at or above the boiling point, and any volume equal to or greater than the specific volume for saturated steam at the same pressure.

Fourth: The difference between the temperature of the steam in this vessel and 228 deg. F. is the degree of superheat. If the thermometer registers 328 deg. F. the steam is said to have 100 degrees superheat.

Steam is superheated when it has been heated above the temperature corresponding to the saturation temperature. If heat is abstracted from saturated steam it will condense.

If pressure is released from a vessel containing saturated steam and water, some water will evaporate as it absorbs the heat given up in reducing the steam and water to the temperature corresponding to the lower pressure. If the pressure is raised by forcing steam into the vessel, some steam will condense as the rest of the steam and water absorb heat from it necessary to raise this temperature to that corresponding to the higher pressure.

Application of Superheated Steam

So far as is known, the first practical application of superheated steam was made in 1828. Its use increased gradually until about 1870, but from then until 1895 its use decreased. During this period compound engines were developed and mineral cylinder oils suitable for high temperatures were not available.

During the past twenty-five years there has been a tremendous change in boiler practice in stationary plants. Figs. 90 and 91 show the progress and tendencies in average boiler sizes, pressures, furnace volumes, turbine capacities and steam temperatures from 1900 to 1926.

It is interesting to note that the steam turbine, in which superheated steam shows the least theoretical economy of any prime mover, has during the past twenty-five years forced the development of superheated steam at a rapid rate.

During this same period 100,000 simple non-condensing reciprocating locomotives have been fitted with super-

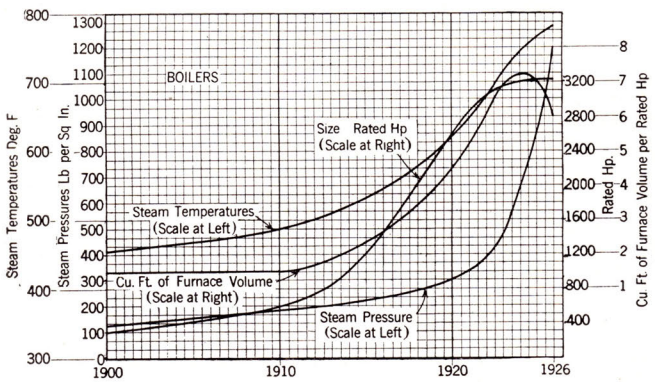


FIG. 90 Progress and Tendencies of Steam Pressures, Temperatures and Furnace Volumes Since 1900.

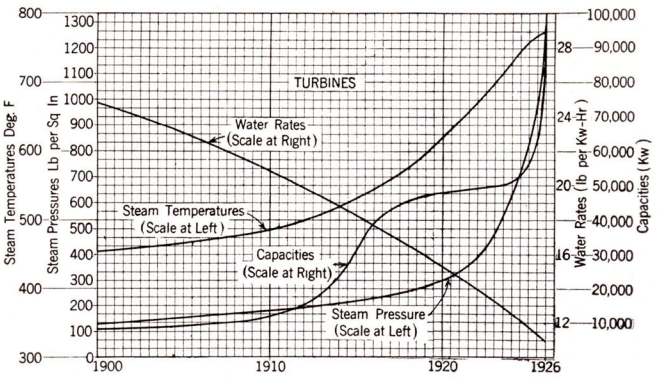


FIG. 91 Progress and Tendencies of Steam Pressures, Temperatures and Turbine Water Rates Since 1900.

*Reprinted in part from Superheat Engineering Data, a Handbook on the Generation and Use of Superheated Steam and Related Subjects, Seventh Edition Revised, 1927, price, one dollar.

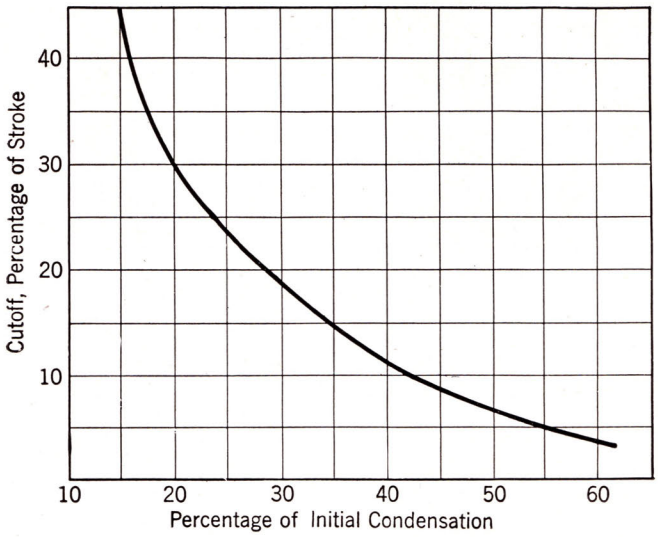
heaters, delivering steam at an average pressure of 200 lb., and average superheat of about 250 deg. F., making the average total temperature of the steam 638 deg. F. Many locomotives are operating satisfactorily with total steam temperatures of 750 to 800 deg. F., which shows that the development of lubricating oil has kept pace with the development of high steam temperatures. The same can be said in regard to insulation, packing, valves and pipe fittings.

Total steam temperatures of 450 to 500 deg. F. generally can be handled satisfactorily in any existing stationary or marine plant with reciprocating engines designed for saturated steam. If the total temperature includes 100 degrees superheat, an economy of at least 15 per cent can be obtained.

Up to total temperatures of 500 deg. F., no special precautions are as a rule necessary. With steam temperatures above 500 deg. F., however, the expansion and packing problems relating to prime movers and piping should be carefully studied. In this connection it is well to note that all the cylinders, steam chests and steam pipes connecting them with the superheater on locomotives are made of cast iron and failures of such parts are as infrequent as when saturated steam was used. It seems, therefore, that the prejudice against the use of superheated steam in existing plants is the result of incorrect conclusions drawn from occasional failures.

Why Superheated Steam Is Used

The amount of work it is possible to obtain from steam in a prime mover depends entirely upon the total heat that can be released for doing work; the higher the pressure, the greater is this heat, and for this reason the tendency has been toward higher pressures. With saturated steam the heat available depends entirely upon the pressure, while with superheated steam there is additional heat, proportionate to the degree of superheat. Superheat makes steam more nearly a perfect gas. One of the properties of a perfect gas is that the internal energy depends on the temperature, so that the more nearly steam becomes a perfect gas the better it does its work.



Marks' Mechanical Engineers Handbook

FIG. 92 The Direct Relation Between the Ratio of Expansion and the Moisture in the Steam at the Point of Cutoff.

The principal advantages obtained through the use of superheated steam are occasioned by the increased volume of steam delivered per pound of water evaporated and the prevention of condensation in steam pipes, cylinders and turbine casings. The economies which result from these advantages are in nearly direct proportion to the increase in superheat temperatures. The greater the degree of superheat, the more reluctant is steam to give up its heat, and the temperature loss from the boiler to the prime mover with high superheat is less than with either low degrees of superheat or with saturated steam.

Reciprocating Engines

Thermodynamically, the work which a reciprocating engine is capable of doing depends upon two factors:

(a) The volume and pressure of the steam delivered.
(b) The absence of moisture in the cylinders.

In relation to the first factor, the object is to fill the cylinder to the point of cutoff with the required volume, but with the least weight of steam. At a given pressure the volume of steam is a direct function of its temperature and the higher the temperature, the less weight required.

With reference to the second point, there can be no reduction of the temperature of saturated steam without the formation of moisture, as has been explained. Evidently the greater this moisture or condensation, the greater is the saving made possible by the use of superheated steam.

The degrees of superheat necessary to prevent cylinder condensation vary with the ratio of expansion. Fig. 92 shows the initial cylinder condensation which may be expected at various points of cutoff with initially dry saturated steam. Fig. 93 shows the amount of superheat necessary to eliminate all cylinder condensation. About 7½ degrees of superheat is required to eliminate each one per cent of moisture in a cylinder *at time of cutoff*.

The economy due to superheat in an engine cylinder can be shown readily by the following example:

Assume that an engine cylinder to point of cutoff has a volume of 2 cu. ft., boiler pressure 215 lb. gage or 230 lb. absolute, and 200 degrees superheat, cutoff at 30 per cent of stroke. Referring to the steam tables, the following values for 230 lb. absolute pressure are found:

*Cu. ft. per lb.—saturated steam	2.00
Cu. ft. per lb.—superheated steam (200 deg. F.)	2.67
Total heat per lb.—saturated steam	1200 B.t.u.
Total heat per lb.—superheated steam (200 deg.)	1312 B.t.u.

Referring to Fig. 92 it is found that with saturated steam the initial condensation probably will be 20 per cent, while with superheated steam, Fig. 93 shows that about 150 degrees of superheat will be required to eliminate this amount of initial condensation. The volume before expansion would therefore be that corresponding to 200 − 150 or 50 deg. of superheat; namely, 2.18 cu. ft. per lb.

With saturated steam and 20 per cent of initial condensation, 20 per cent more steam has to be introduced so that the total heat to give 2 cu. ft. before expansion would be $1200+(.20\times1200)=1440$ B.t.u. With super-

*Note: There is a 33⅓ per cent increase in volume with only 9⅓ per cent increase in heat.

heated steam it would be necessary to introduce only $\frac{2}{2.18}=0.917$ lb. of steam, the total heat of which would be $1312\times0.917=1203$ B.t.u. in order to fill the 2 cu. ft. This means a heat saving or fuel saving of 16½ per cent by using 200 degrees superheat, as compared with saturated steam.

The steam consumption with saturated steam would be 1.2 lb. as compared with 0.917 lb. for 200 degrees superheat or a steam saving due to superheated steam of 23.6 per cent.

The increase in economy, due to increasing the superheat, may be shown by carrying the above example farther and assuming that 250 degrees superheat is used, instead of 200.

The volume of superheated steam has been increased to 2.82 cu. ft. per lb. and the total heat to 1336 B.t.u. This represents an increase of 41 per cent in volume over the saturated steam with only 11 1/3 per cent increase in heat and an increase of 5.6 per cent in volume over 200 degrees superheat with only 2 per cent increase in heat.

Since, as above, 150 degrees of superheat will be required to eliminate initial condensation, the volume before expansion would be that corresponding to 250−150 or 100 degrees of superheat; namely, 2.35 cu. ft. per lb. with 250 degrees superheat. Therefore it would be necessary to introduce only $\frac{2}{2.35}=0.851$ lb. of steam, the total heat of which would be $1336\times0.851=1137$ B.t.u. in order to fill the 2 cu. ft. This means a heat saving or fuel saving of 21 per cent by using 250 degrees superheat, as compared with saturated steam, or 5½ per cent more saving as compared with 200 degrees superheat. Furthermore, since the steam consumption with 250 degrees superheat would be only 0.851 lb. as compared with 1.2 lb. for saturated steam, there would be a steam saving due to the superheated steam of 29.1 per cent, or 7.2 per cent more for 250 degrees superheat than with 200 degrees superheat.

The percentage of steam saving ordinarily is greater under unfavorable conditions. The actual amount of condensation or the heat absorbed by the cylinder and the reduction of superheat before the cutoff will depend upon the speed or number of revolutions of the engine. The lower the speed and the longer the steam stays in the cylinder, the more heat will be absorbed by the cylinder. It will also depend upon whether or not the cylinder is jacketed and upon the outside cylinder insulation.

The opinion frequently has been advanced that the mean effective pressure in cylinders using superheated steam is altered from that existing when saturated steam is used; the initial pressure, the point of cutoff and piston speed, of course, being assumed as the same in each case. This increased cutoff is necessary only when the ratio of expansion is high; either in multiple cylinder engines or at extremely short cutoffs in single expansion engines. It is true that the pressure of expansion (immediately after cutoff) may be slightly lower with superheated steam, but, for the same reason, the back pressure will be less with the result that the mean effective pressure will be approximately the same in both cases.

But consideration of the possibility of increased engine power, due to superheating, must not stop here. Consider a saturated steam plant in which the boilers are operating at their full capacity to supply the steam demanded by the prime movers. Take this same plant and superheat it—the decrease in steam consumption per horsepower-hour will result in a reserve boiler capacity which will make possible either the operation of the boilers at lower rating or will furnish the additional steam necessary to meet an overload on the prime mover. In other words, superheating makes it possible to increase the power which the prime mover may develop over what it could produce with saturated steam.

In new installations the use of superheated steam permits the use of engines having larger cylinder diameters and enables them to be operated with shorter cutoffs. Because cylinder condensation is eliminated, the gain in economy due to a more effective expansion of the steam is realized.

Engine manufacturers are now recommending steam temperatures of 500 deg. F. for engines of the Corliss and slide valve types, and up to 650 deg. for engines of the piston and poppet valve types.

It is, however, an assured fact, and a good reason for the more general adoption of high degree superheat, that only engines designed for high degrees of superheat

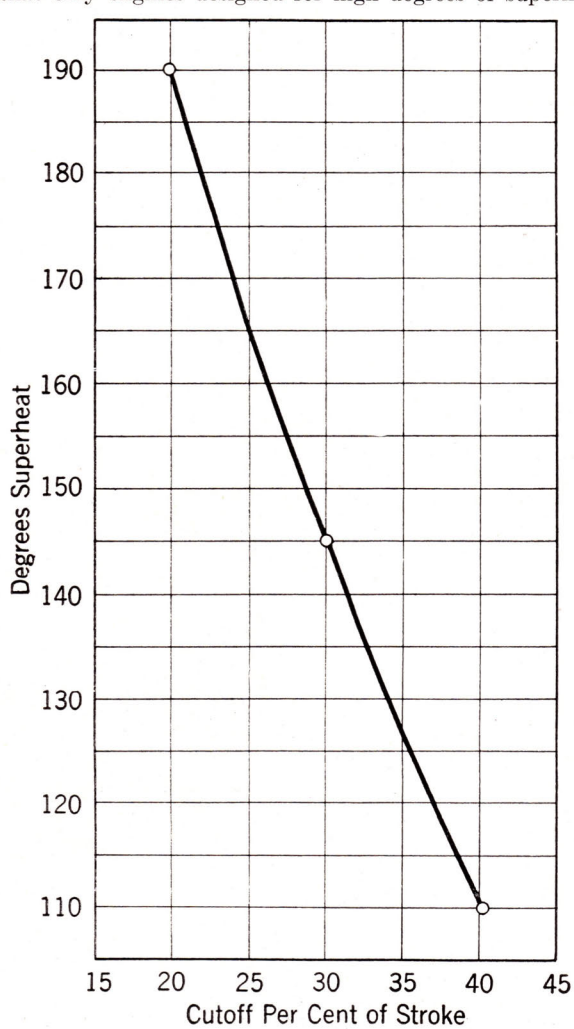


FIG. 93 Superheat Required to Prevent Condensation for Various Ratios of Expansion in Reciprocating Engines.

and using it can successfully compete in economy in the power generation field.

The exhaust steam from engines operating on superheated steam contains almost as many heat units as the exhaust from engines operating on saturated steam. As the exhaust of the former contains much less moisture, superheated steam is preferable for many industrial processes functioning on exhaust steam.

TABLE 1 STEAM CONDITIONS IN TURBINE

Steam Chest	Stages										
	1	2	3	4	5	6	7	8	9	10	
265	120	68	48	28	16	9	4.7	2.4	1.1	0.5	lb. abs. pres.
Degrees Superheat					Per Cent Moisture						
250	160	120	75	30	0.6	2	4	6.5	8	10.5	Qual. of Stm.
656	501	421	354	277	216	188	160	133	107	79	Temp. Deg. F.

TABLE 2 RANGES IN STEAM CONSUMPTION OF PRIME MOVERS

Showing the approximate saving which may be expected due to the use of superheated steam in various types of prime movers.

Type Engine	Steam Consumption, lb. per hp.-hr.		
	Saturated Steam	100 deg. Superheat	200 deg. Superheat
Simple non-condensing	29–45	20–38	18–35
Simple non-condensing automatic	26–40	18–34	16–30
Simple non-condensing Corliss	26–35	18–30	
Compound non-condensing	19–28	15–25	13–22
Compound condensing	12–22	10–20	9–17
Simple duplex steam pumps	120–200	80–160	
Turbines non-condensing (kw.-hr.)	28–60	24–54	21–48
Turbines condensing (kw.-hr.)	12–42	10–38	9–34
Simple non-condensing locomotive	27	23	19.5
Steam Shovels	42	34	29

Turbines

High degree superheat is of vital importance in steam turbines. All turbine plants of any size are now using superheated steam; several plants operating with superheat up to 250 deg. F., and over. Turbine manufacturers have made a strong claim in favor of turbines in which high degrees of superheat can be used.

The saving attributable to the use of superheated steam in turbines is partially due to the increase in volume of the steam, but the major saving is because of the fact that the absence of moisture decreases the frictional losses, which are unavoidable in greater or lesser degree, in the passage of the steam through the nozzles and among the blades and vanes. This is particularly true at high velocities.

The windage loss or friction between the rotor and enveloping vapor is also reduced by using superheated steam because of its lower density, and the absence of moisture.

It has been found by experience that in an average-sized turbine using steam with about 250 degrees superheat, the losses in blades and nozzle are decreased 1 per cent for every 10 degrees of superheat. The decrease in economy for any stage is about double that represented by the percentage of moisture in the steam. For example, if the steam entering the stage has 1 per cent moisture, then the decrease in economy in that stage will be nearly 2 per cent. With 5 per cent of moisture the decrease will be about 10 per cent.

The entropy of low pressure steam is higher than that of high pressure steam. Therefore if saturated steam expands adiabatically in a turbine, a part of the steam is *necessarily* converted into water. With saturated steam the moisture content of the live steam entering the turbine is gradually increasing throughout the lower stages and accordingly decreasing the efficiency of those stages. When superheated steam is expanded in doing work no condensation occurs, only the superheat gradually diminishes, and no moisture is present as long as the steam is superheated.

The internal surfaces of a turbine are largely increased beyond those in reciprocating engines, and the effect of temperature range in augmenting condensation is very great, even though the temperature in the turbine changes neither so frequently nor so widely.

Moisture is particularly damaging to steam turbines. It reduces the efficiency by the excessive friction between the water and turbine parts. One authority points out that a turbine without superheat is merely a form of water brake. Every ounce of water passing through, no matter how finely divided, is inert material, and serves only to check the running of the rotor. But that is not all. The condensate is mixed with air, hence has a corrosive action on the blades and vanes of the turbine. It is also very erosive, wearing away blading quite rapidly, thus calling for more frequent renewals and shutdowns than when superheated steam is employed. When saturated steam is used, economy steadily drops, and the maintenance cost steadily rises.

Superheated steam not only saves fuel in the operation of turbines, but also is instrumental in raising and maintaining the average efficiency and lowering the cost of maintenance, while permitting a turbine to remain in service longer without the replacement of blades, vanes, etc.

The *General Electric Review* of March, 1918, gives the data on a multi-stage turbine test reproduced in Table 1. It will be noted that no moisture is shown until the steam is expanded from 265 lb. down to about 20 lb.

Pipe Lines

With a pipe carrying dry saturated steam, any heat radiated causes a part of the steam to be condensed, and the condensate, particularly for long pipes, is not returned to the boiler but is discharged through traps and wasted. Therefore, in addition to the direct heat lost by radiation

there is a further loss of the liquid heat of the condensate, which in some cases, particularly for high pressure steam, may amount to 25 per cent of the radiated heat. With superheated steam, however, radiation represents a decrease only in the amount of superheat, neglecting loss of pressure and no condensation occurs as long as the steam remains superheated, so that no additional heat besides that radiated is wasted.

As the thermal conductivity of superheated steam is much lower than that of dry saturated steam, heat is transmitted less rapidly to the pipes, hence radiation and condensation losses are much less than with saturated steam. Superheating steam also eliminates water hammer and its attendant engine and pipe troubles.

It is a matter of historical interest that the first recorded use of superheated steam was necessitated by the condensation which took place in a long steam line.

In many power plants the prime movers are located at long distances from the boilers supplying the steam. The long pipe lines carrying the steam often are run out of doors, where they are exposed to all kinds of weather. As the length of the steam lines increases and the volume of steam increases, economy goes down and condensation losses multiply. Proper superheating not only eliminates these losses, but also increases the capacity of existing steam lines simultaneously with an increase in economy.

Long pipe lines carrying saturated steam can be used for superheated steam without any change, resulting in a great saving in the available heat and quantity of steam delivered for power purposes. This fact alone should make the use of superheated steam a universal practice on long pipe lines.

In many industrial processes, such as the production of edible and mineral oils, glycerine, soaps, sugar, and so on, steam is used on a large scale. Keeping transmission lines and heating surfaces dry saves fuel and lessens the time of treatment. Drip losses through condensation are almost invariably underestimated. A 5 per cent loss from this cause is very conservative for an average plant.

When condensation in steam lines is reduced, both steam and coal are saved, because in the generation of steam about nine-tenths of the heat absorbed by the water in evaporating it and raising the steam pressure is latent heat. When steam is condensed, latent heat is liberated, and unless it performs useful work it is wasted. Condensation, therefore, occurring in pipe lines represents a definite waste of nine-tenths of the heat, and if the condensate is not returned to the boiler all that heat is wasted. By adding a sufficient amount of superheat to the steam, the temperature can be raised to a point where all of the steam may be transmitted to its destination and used without condensation losses.

Aside from fuel saving, it should be kept in mind that reduced steam consumption also means smaller piping is required. In many plants this is an important factor, particularly where the demand for steam in various parts of the plant has been increased materially since the plant was designed. Higher velocity can also be used safely in pipe lines.

John H. Lawrence states he has found that it is good practice to figure steam pipe sizes allowing a velocity of 1,000 ft. per min. per inch of pipe diameter up to 15-in. pipe, which is the ordinary maximum velocity for pipes larger than 15 inches. For instance, the proper velocity for 2-in. pipe is 2,000 ft. per min., while for 6-in. pipe it is 6,000 ft. per min.

In many cases these velocities may be increased; for heating purposes up to 50 per cent.

Boilers

A definite amount of heat is required to superheat steam to a certain temperature, and this heat is furnished by the fuel. Assume a boiler designed without a superheater giving the highest practical thermal efficiency. Suppose a properly designed superheater is installed in this boiler. It will be found that the overall thermal efficiency of the combined boiler and superheater will be greater than the boiler without the superheater when evaporating the same amount of water, because by the addition of the superheating surface more heat is absorbed and the final uptake gas temperature is lowered. The increase in efficiency varies with the rate of evaporation, and generally will average from 2 to 5 per cent. This result can be accomplished, however, only when the superheater is correctly designed so as not to obstruct unduly the flow of the gases through the boiler. Undue obstruction to the gases would decrease the overload capacity of the boiler.

Additional economies result to the boiler from superheating steam. Boiler heating surfaces are called upon for less work in developing the same power, hence fewer boilers are needed, and less manipulation and banking of fires suffice. All this means fuel saving and lower maintenance costs chargeable to the use of a superheater.

Inversely, as less boiler heating surface is required when superheating, it follows that for the same output station capacity is increased. Expressed differently, the installation of superheaters increases the capacity of the plant, boilers, pipe lines and prime movers.

The upkeep cost of superheaters is very low compared with that of boilers; the initial cost also is lower. Much less attention is required. When superheaters are installed there is less work for stokers, furnaces and boilers, furnace linings and bridge walls. Boiler tubes are also subjected to less severe conditions and there is a tendency for maintenance costs to lower. It often is more economical to install superheaters than to add boiler heating surface by putting in more boilers.

Superheated Steam in Existing Plants

That a superheater may be installed in the gas passages in the boiler is a factor that is of immense advantage for the existing plant. It means that a superheater installation may be made without radical changes in the plant; all that is necessary is to put in the superheater and connect it to the boiler and steam lines.

Installing a superheater merely means doing one thing in one place and so bringing about many advantages in many places; namely, more economical operation of boiler, steam lines, prime movers and auxiliaries.

The capacity of existing steam lines that are overloaded can be increased by superheating the steam, thus permitting better pressure regulation, heavier loads and lower frictional and radiation losses. Likewise, the lower steam consumption of prime movers that accompanies superheating is equivalent to increasing plant capacity. Superheaters cost less initially per unit of heating surface than

boiler heating surfaces. They also cost less to maintain. As they save fuel it is preferable, when feasible, to install superheating surface rather than additional boiler heating surface.

Not uncommonly, old boilers must be operated at reduced pressure on the score of safety. Economy and capacity suffer accordingly. Again, as the uses for steam multiply and the transmission distance extends around a plant, return drainage, condensation, radiation and friction become more troublesome. By installing superheaters, the objections to reduced steam pressures may be counteracted; capacity may even be increased simultaneously with economy, and transmission losses reduced or entirely eliminated.

The advantages of superheating steam in existing plants are so great and they may be obtained so easily and relatively so inexpensively that many existing power plants now operating with saturated steam should consider the use of superheated steam.

Most plants will operate profitably and safely on superheated steam. It should be borne in mind, however, that the higher the superheat, the greater the economy, so that in considering the use of superheaters the highest practical degree of superheat consistent with plant conditions should be adopted, so that the full advantage of superheated steam may accrue.

The improvement effected by superheated steam in a plant having H.R.T. boilers with Elesco superheaters is shown by test data in Table 3.

TABLE 3 RESULTS OF TESTS IN A PLANT HAVING H.R.T. BOILERS EQUIPPED WITH ELESCO SUPERHEATERS

Tests were made about two weeks apart with flues in approximately the same condition. Duration of tests—4 hours each. Machine shop only under constant load conditions at night.

	Saturated Steam	Superheated Steam	Per Cent Increase	Per Cent Decrease
Total Coal Consumed—Lb.	9,316	6,827		**26.7**
Steam Consumption—Lb. of Water	57,500	46,000		**20.0**
Average Steam Pressure of Boilers—Lb.	118.0	115.0		2.5
Aver. Load on Corliss Engine—I. Hp.	43.0	43.6	1.4	
Aver. Load on Woodmill Engine—I. Hp.	43.2	42.8		0.9
Aver. Load on Electric Generator—Kw.	56.7	56.8	0.2	
Revolutions of Air Compressor—Total	26,590	26,630	0.1	
Boiler Hp. Developed	386	336		12.9
Per Cent Rated Capacity Developed	107.0	93.3		....
Efficiency of Boiler, Furnace and Grate	47.6	57.7	**21.2**	
Temp. Feed Water—Deg. F.	212	207		2.4
Heat Value—B.t.u. per Lb. Coal	13,510	13,190		2.4
Degrees Superheat — Main Header	.....	163	....	....

SUMMARY:
26.7 per cent saving in fuel.
20.0 per cent saving in water.
21.2 per cent increased efficiency.

Superheater Design and Performance

Integral Superheaters

In most cases superheaters are installed within the boiler setting and receive their heat from the same flue gases and same furnace as the boiler. Such superheaters are called "integral superheaters."

Integral superheaters generally are of the convection type, absorbing heat from the gases of combustion which sweep over them. In the case of water tube boilers used in stationary or marine practice, the superheater is located, in most instances, between the first and second passes or in the first tube bank. In standard cross and longitudinal drum boilers where the superheater is located above the tube bank it is known as a convection type superheater. In semi-vertical boilers, when located between tubes of the first bank, the superheater units receive a small proportion of radiant heat, according to proximity to the furnace. Integral superheaters sometimes are located behind water-cooled furnace walls, where they absorb heat only by radiation and are known as radiant superheaters. In some cases they act as boosters or reheaters.

In horizontal return tubular boilers the superheater is customarily located in the rear of the combustion chamber.

In locomotive type and Scotch marine boilers experience has shown that the fire tube type superheater is the fundamentally correct design. The Elesco fire tube superheater consists of loops of tubing forming superheater units, which extend into the boiler flues and are supported in the center of the latter so that the gases of combustion sweep their entire exterior surface.

In stationary water tube boilers the superheater should be located in a suitable temperature zone so that there will be a temperature difference between gases of combustion and steam temperature desired of at least 300 deg. F. The degree of superheat also may be affected appreciably by radiant heat if superheater is located low in the first pass. The effect of convection heat due to gases passing through the superheater usually causes the superheat to rise as the boiler rating increases up to a certain point and then drop off as rating increases. If the average rating is known in advance the superheater can be so designed that the desired superheat will be obtained at the point of average rating and slight changes of load will have little effect on the superheat. This general performance is dependent on the fact that to produce more steam more fuel is burned and there is a greater volume of furnace gases with a consequent increase in gas and steam velocities.

In addition, the gas temperatures are higher regardless of the superheater location. The rate of heat transfer increases slightly as the temperature increases and rapidly as the velocities increase.

There is another factor, however, which rather tends to keep the superheat from rising with the rating; that is the per cent of moisture in the steam entering the superheater. Most boilers deliver more moisture at the higher rating. One per cent moisture will reduce the superheat 16 to 17 deg. F.

The general efficiency of the design and operation of any boiler has a definite effect on the superheater performance. Taking 12 per cent CO_2 as a basis for comparison, stack temperatures will increase from 1 to 4 per cent for each

1 per cent decrease in CO_2. Superheat will increase from 3 to 10 per cent for each 1 per cent decrease in CO_2.

It is needless to say that soot on superheater tubes will reduce the heat transfer very materially. On account of the small diameter bare tubing of the Elesco design, the effect of soot accumulation is reduced to a minimum.

To prevent short circuiting of steam at low loads the saturated steam inlet and the superheated steam outlet should always be located at opposite sides of the setting.

The practice of flooding superheaters in starting a boiler has practically been abandoned as unnecessary and objectionable. All of the steam generated by the boiler should pass through the superheater. It is for this reason that a safety valve, set a few pounds below the main boiler safety valve, is located at the outlet of the superheated steam header of a superheater. When the boiler reaches the limit at which the superheater safety valve is set and the valve blows off, it will draw steam through the superheater and thus eliminates the possibility of the superheater being left exposed to the extremely hot gases without steam flowing through it. This condition is quite different from that which exists when a boiler is started up. In the latter case, the drip valve in the superheated steam header is left open and the boiler tubes absorb the heat of the gases so fast that when they reach the superheater, they are sufficiently cool and the first steam generated protects the superheater without resorting to flooding.

Thousands of Elesco superheaters have operated for years under all kinds of water conditions without a trace of deposit of sediment or scale in them. This has been accomplished because the tubes are small in diameter and uniform in area throughout their length. The steam passes through at a high and uniform velocity.

With proper steam velocity through the superheater, there will be no scaling inside the tubes if flooding is not practiced and dry saturated steam enters the superheater. If the water is extremely bad, the saturated steam should pass through an effective dry pipe or purifier before entering the superheater.

Up to recent years superheaters for horizontal water tube boilers were located almost exclusively above the main bank of tubes or between the first and second gas paths. In this location the temperature of the gases was only sufficient for comparatively low superheat and the superheat varied with the rating of the boiler. For low average superheat these temperature fluctuations are of little consequence, since in any case the final temperature is not excessive.

With increased pressure and superheat, reasonably constant temperatures are imperative, as wide temperature fluctuations cause additional stress in the prime mover, which may become detrimental.

In Europe special temperature regulators were designed and often applied with superheaters for high temperatures. American engineers have approached the problem from another angle. Proceeding from the fact that any load variation affects both boiler and superheater, since the same amount of steam that is generated by the boiler passes through the superheater, the superheat will be constant if the heat absorbed by both boiler and superheater varies in the same proportions. On the other hand, it is a known fact that the first few rows of boiler tubes gen-

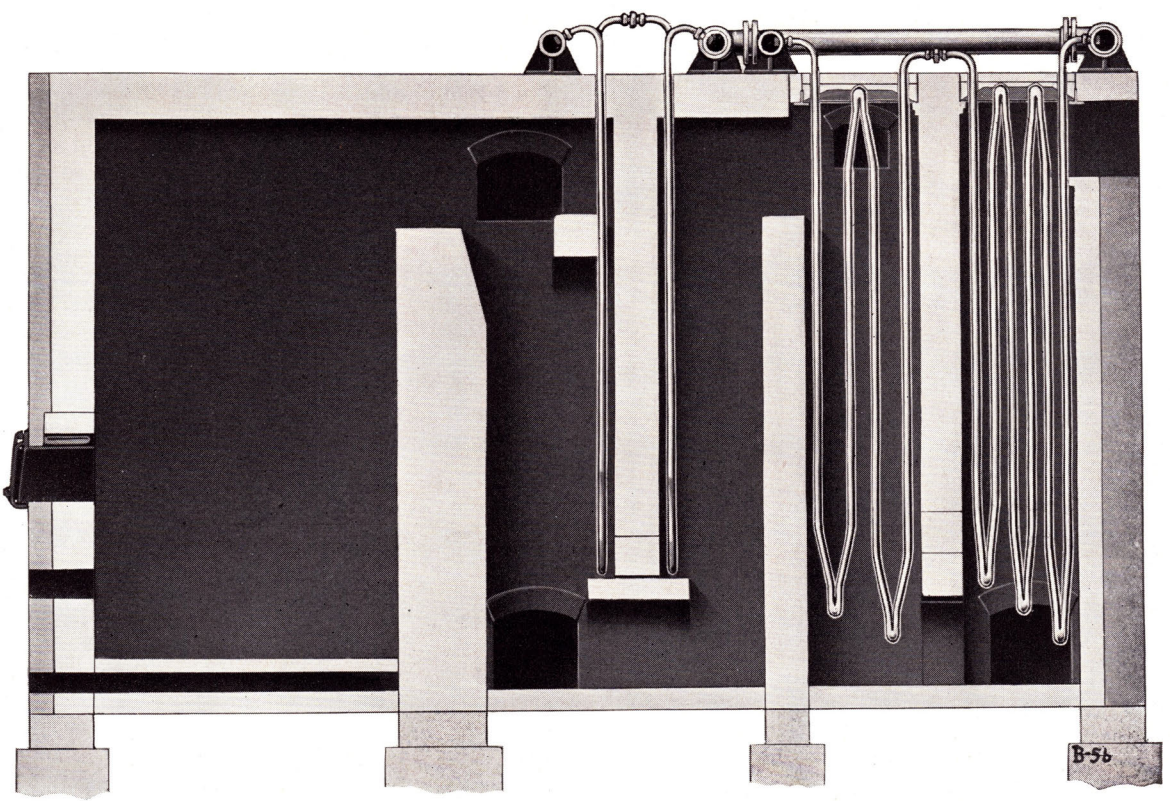


FIG. 94 Elesco Separately Fired Superheater. A Multiple Unit Design for Superheating from 3000 to 200,000 Lb. Steam per Hour.

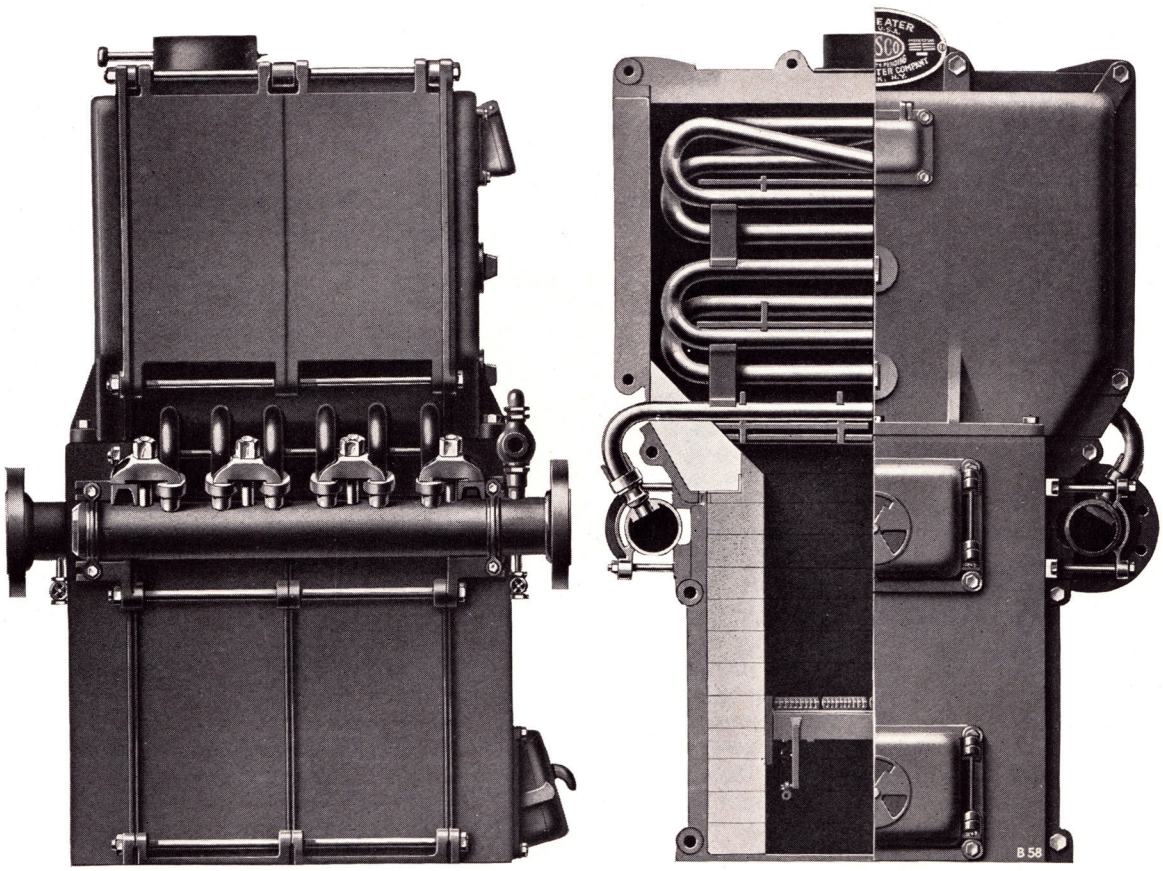


FIG. 95 Elesco Portable Superheater. For Standard Sizes see Table 4.

erate most of the steam, so that a superheater located between or near these tubes will be subjected to the same variation as that part of the boiler where most of the steam is generated, and in this way approach closely the ideal conditions for constant temperatures.

This arrangement was first applied in the 2647-hp. boilers (Fig. 27) at the *Fordson* plant of the *Ford Motor Company,* where the superheater units were located between the boiler tubes of the first bank. The remarkable results obtained by this installation have encouraged us to apply the same principle in designing superheaters for other types of boilers. Since then a number of installations with Elesco superheaters in this location have been put in operation, every one of which has borne out this theory.

Separately Fired Superheaters

In some instances superheaters have to be provided with their own furnaces:

First: When the design of the boiler does not permit the installation of an integral superheater.

Second: When the steam must be used highly superheated at a considerable distance from the boiler.

Third: When one boiler or a battery of boilers is supplying steam for different purposes, not all of which are using superheated steam.

Separately fired superheaters often are used where only a part of the steam is to be superheated or part is to be superheated to a higher degree than the rest, as may be the case in chemical processes, such as mineral oil refining, vegetable oil deodorizing or pulp digesting.

Elesco separately fired superheaters of type shown in Fig. 94 can be built in brick settings for capacities from 3000 to 200,000 lb. of steam per hour with an efficiency of 70 to 75 per cent.

Elesco portable superheaters, Fig. 95, are available for capacities up to 3000 lb. of steam per hour, as shown in Table 4.

In either of these types of separately fired superheaters the superheat can be regulated at will by the amount of fuel burned.

TABLE 4 ELESCO PORTABLE SUPERHEATER

Standard Sizes for Pressures Up to 200 Lb. Only Slight Changes Required for Higher Pressures.

Size	No. 1		No. 2		No. 3	
Capacity, Lb. Steam....	1000	600	2000	1200	3000	2000
Superheat, Deg. F.....	100	200	100	200	100	200
Height.....	5′ 3″		5′ 3″		5′ 3″	
Floor Space.....	3′ 6″ x 3′ 6″		3′ 6″ x 4′ 6″		3′ 6″ x 5′ 6″	
Weight lb.....	2400		3200		3900	

Variables Affecting the Design of a Superheater

The design and resultant operating characteristics of any superheater integral with the boiler depend not only on the design of the boiler and location of the superheater with relation to the boiler heating surfaces, but also on several other factors, any one of which may materially affect the results obtained.

Data regarding the steam usually are known. These include quantity of steam in pounds per hour, superheat in degrees F., mean specific heat of the steam and steam temperatures at both inlet and outlet of superheater.

The coefficient of heat transmission gives the heat in B.t.u. per hour which can be transmitted under the given conditions from the gases to the steam per square foot of heating surface per degree difference in temperature between gases and steam. This factor depends very largely on the amount and velocity of the gases, the velocity of the steam, the temperature difference between the gases and the steam, the type of superheater, the sizes of the tubes, etc.

The temperature of the gases, however, very seldom is given. The gas temperature at superheater inlet depends on the location of the superheater, kind of fuel, method of firing, the conditions of the boiler heating surface, etc. The fall of the gas temperature through the superheater or the difference between gas temperature at superheater inlet and superheater outlet depends on the amount of gases available or the quantity of gases passing over the superheater. This quantity seldom is known directly.

In order to determine the velocity of the gases, the area of the passage and the amount of the gases are required. The area of the gas passage is fixed by the design of the superheater and its location. The amount of the gases, however, must be determined. To design a superheater, therefore, it is necessary in every case to study the design of the boiler, the arrangement of the furnace, and necessary assumptions must be made regarding the operation of the boiler. Even with a certain temperature of the gases in the furnace the gas temperature at the superheater will vary considerably, depending upon the amount of heating surface passed over by the gases before coming in contact with the superheater units. It is for this reason that in order to proportion a superheater a designer requires information regarding the fuel to be used, the method of firing, the width of the boiler, the baffle arrangement, and the rating at which the desired superheat is to be obtained, so that necessary assumptions can be made correctly as to the amount of gases and their temperature.

Superheated Steam for Heating and Process Work

Steam above 50 lb. gage pressure (65 lb. absolute) rarely is used for heating purposes.

The corresponding temperature for saturated steam is only 298 deg. F.

The question frequently is asked: Why not use superheated steam at low pressure where high temperatures are required for heating and process work?

Suppose we want to heat 1 lb. of water from 300 to 400 deg. F. This requires approximately 100 B.t.u. of heat to be added to it. The temperature of saturated steam at 235 lb. gage (250 lb. absolute) is 401 deg. F. Its latent heat per pound is 826 B.t.u.; therefore if we condense $\frac{100}{826}$ lb. of steam we get our 100 B.t.u. wanted.

Now suppose we take saturated steam at 50 lb. gage, as mentioned above, give it 200 degrees superheat, making its total temperature 498 deg. F. and cool it down to 398 deg. F. to get our heat. The total heat with 200 degrees superheat is 1278 B.t.u. and with 100 degrees superheat 1229 B.t.u. The difference or 49 B.t.u. is all the heat we get out of 1 lb. of steam; therefore we have to cool over 2 lb. of steam to get our 100 B.t.u. wanted instead of $\frac{100}{826}$ lb. as would be the case if we used high pressure saturated steam.

If all the superheated steam used for heating under this condition is used later in a prime mover or in heating feed water there is no objection to heating in this way, but if it is exhausted the waste is obvious.

If it is necessary to have saturated steam for heating work, a portion of the steam can be desuperheated simply and effectively without heat loss by means of a water spray or by bleeding a turbine. Desuperheating by a water spray is not to be recommended when the steam is to be used later in a prime mover.

For industrial process work requiring heat it is good practice to use condensing saturated steam for temperatures up to 250 deg. F. or higher where steam at high pressure is available. Where higher temperatures are required, the conditions are the same as for heating. Superheated steam can be used, particularly if it can be utilized elsewhere after passing the process apparatus. When this is not the case, hot circulating oil may be used for temperatures up to 500 deg. F. and mercury vapor from 500 to 900 deg. F.

Cylinder Lubrication with Superheated Steam

The main difficulties experienced when superheated steam was first used, most of which were due to unsuitable piston rod and valve stem packing and the carbonization of cylinder lubricants employed at that time, have been disposed of. This was accomplished by the substitution of metallic packing for fibrous packing and of high-grade lubricants composed of mineral oils and made especially to withstand the increased temperature conditions. Thus by using the proper mineral cylinder oils, which are now available, superheated steam can be used with no lubrication difficulties whatsoever.

The correct cylinder oil for very high temperature is made from selected crudes, especially treated, and has its best lubricating qualities at temperatures from 600 deg. F. up. To function properly a cylinder oil should meet the following general conditions:

It must retain its viscosity when subjected to the high steam temperatures present.

It must spread readily in order to form a load-supporting and pressure-sealing film between the moving surfaces.

It must resist the washing action of the water of condensation within the cylinder and steam chest.

And it must contain neither ingredients harmful to the engine nor produce gummy carbonaceous or other deleterious deposits.

An unfiltered oil usually is preferred to a filtered oil or "bright stock," as it is termed. In filtering cylinder oil certain elements which give it adhesiveness are removed and, although such oil may atomize readily, the filtering operation reduces its resistance to the washing action of the steam.

An efficient and effective method for the lubrication of cylinders and valves when superheated steam is used is accomplished by feeding from 50 to 75 per cent of the oil to the top of the cylinders with horizontal engines or through the sides of the cylinders with vertical engines and the balance into the steam line ahead of the valve chest with an atomizing tube.

The most efficient manner of feeding cylinder oil to an engine is to feed it by a mechanically operated positive feed lubricator in which the quantity of oil can always be controlled. Such a lubricator consists of an oil reservoir and a pump which supplies a closely regulated and predetermined quantity of lubricant to the steam pipe during each stroke of the piston. The pump is actuated by a rod attached to a reciprocating part of the engine. Since the speed of the pump varies with the speed of the engine, the rate at which the cylinder oil is delivered to the steam main through an atomization nipple is directly proportional to the engine speed. An atomization nipple or tube used to divide the oil into a spray and thus mix it with the steam which will carry it to every cylinder part requiring lubrication and at the same time will use the least possible quantity of oil.

In order to properly lubricate slide valves of engines, grooves should be cut on the surfaces to assist in the introduction of oil between the frictional surfaces and at the same time function as an oil reservoir.

Many different shapes and sizes of oil grooves are found in general practice, the commonest shape being semicircular in cross-section as produced by cutting with a round-nosed chisel. A shallow groove with rounded edges is most acceptable. This groove should be no larger than is necessary to accommodate the quantity of oil required for proper lubrication. Very wide, shallow grooves are objectionable because they rob more bearing surface area than is necessary. The "V" shaped groove with well chamfered edges is not objectionable, excepting for the fact that it has a little less oil capacity than the one with the rounded bottom.

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Illustrations of Elesco Superheater and Boiler Arrangements

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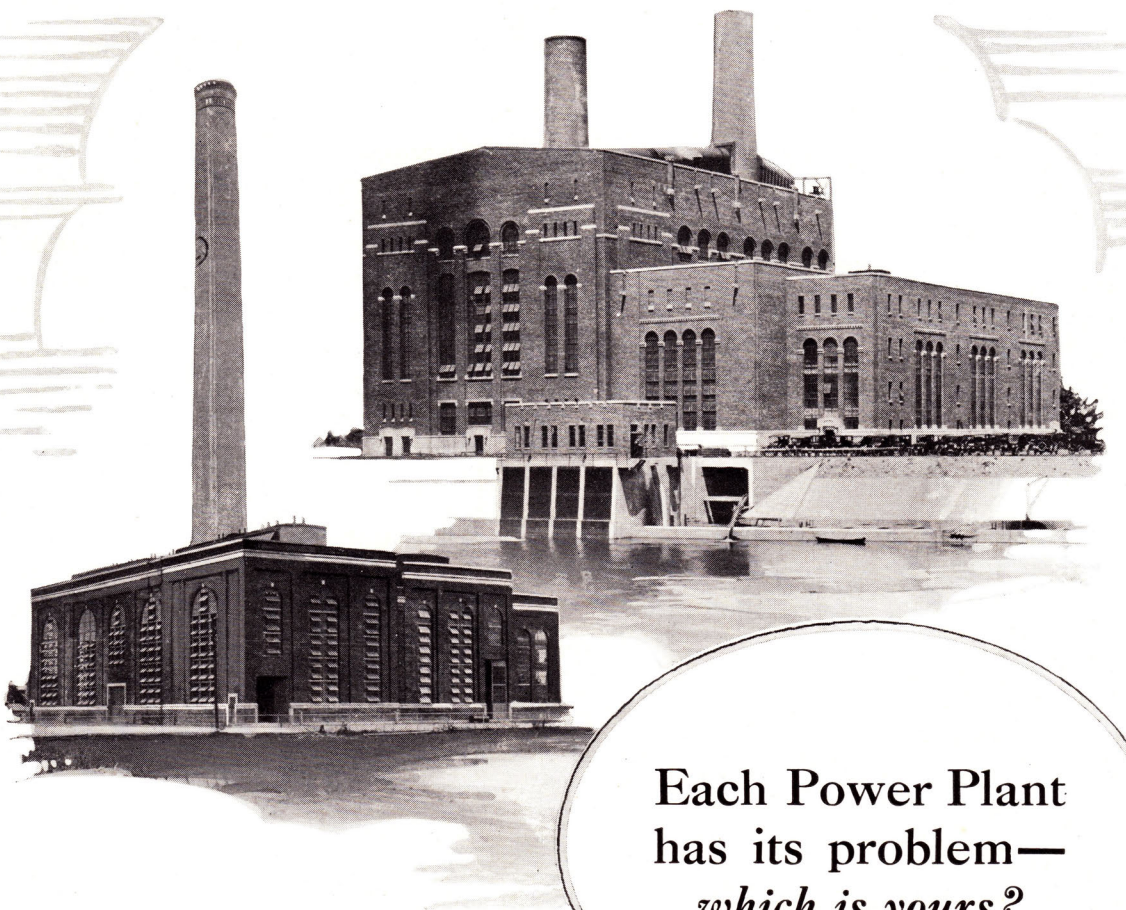

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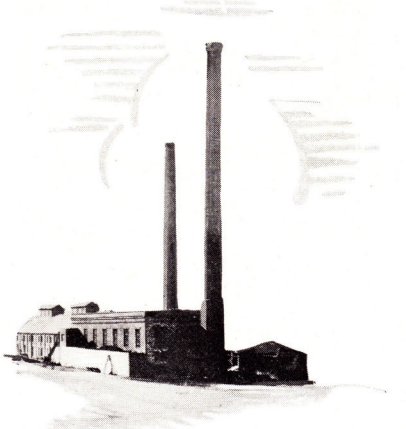

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